NASA's Deep Space Telecommunications Roadmap

C. Edwards

JPL

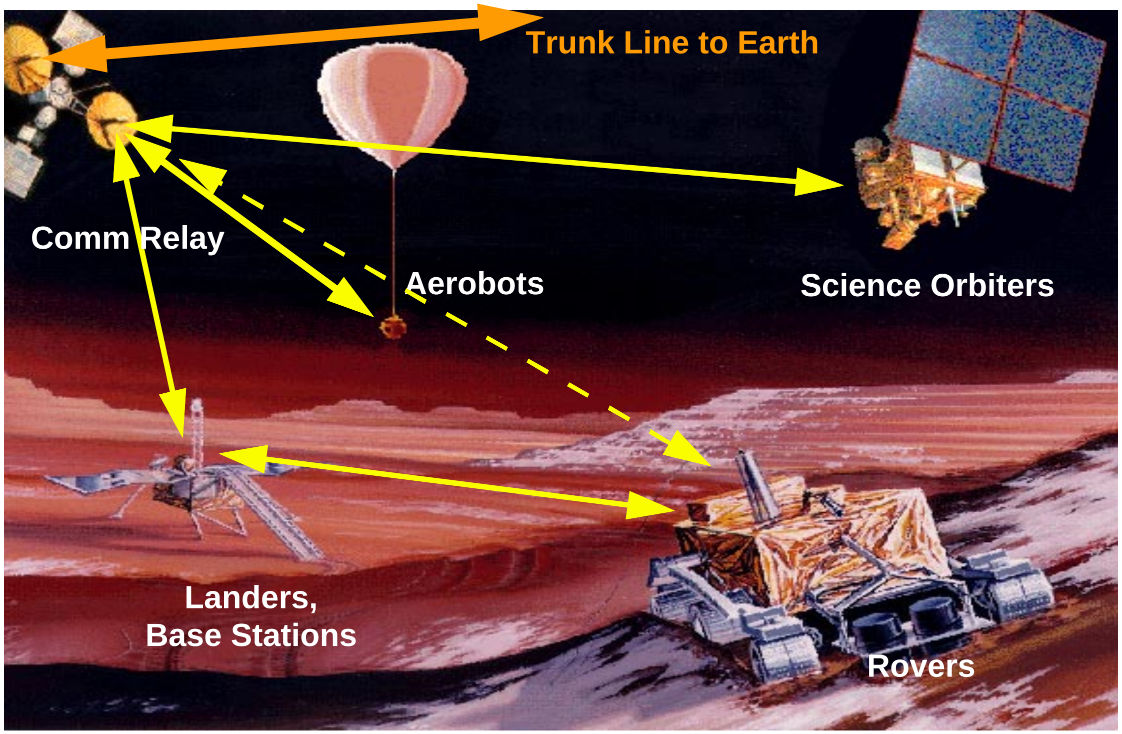
January 22, 1998

Outline

- **Deep Space Telecommunications Challenges**
- **NASA's Deep Space Telecommunications Strategy**
  - **RF Communications Roadmap**
  - **Optical Communications Roadmap**
- **Issues and Recommendations**

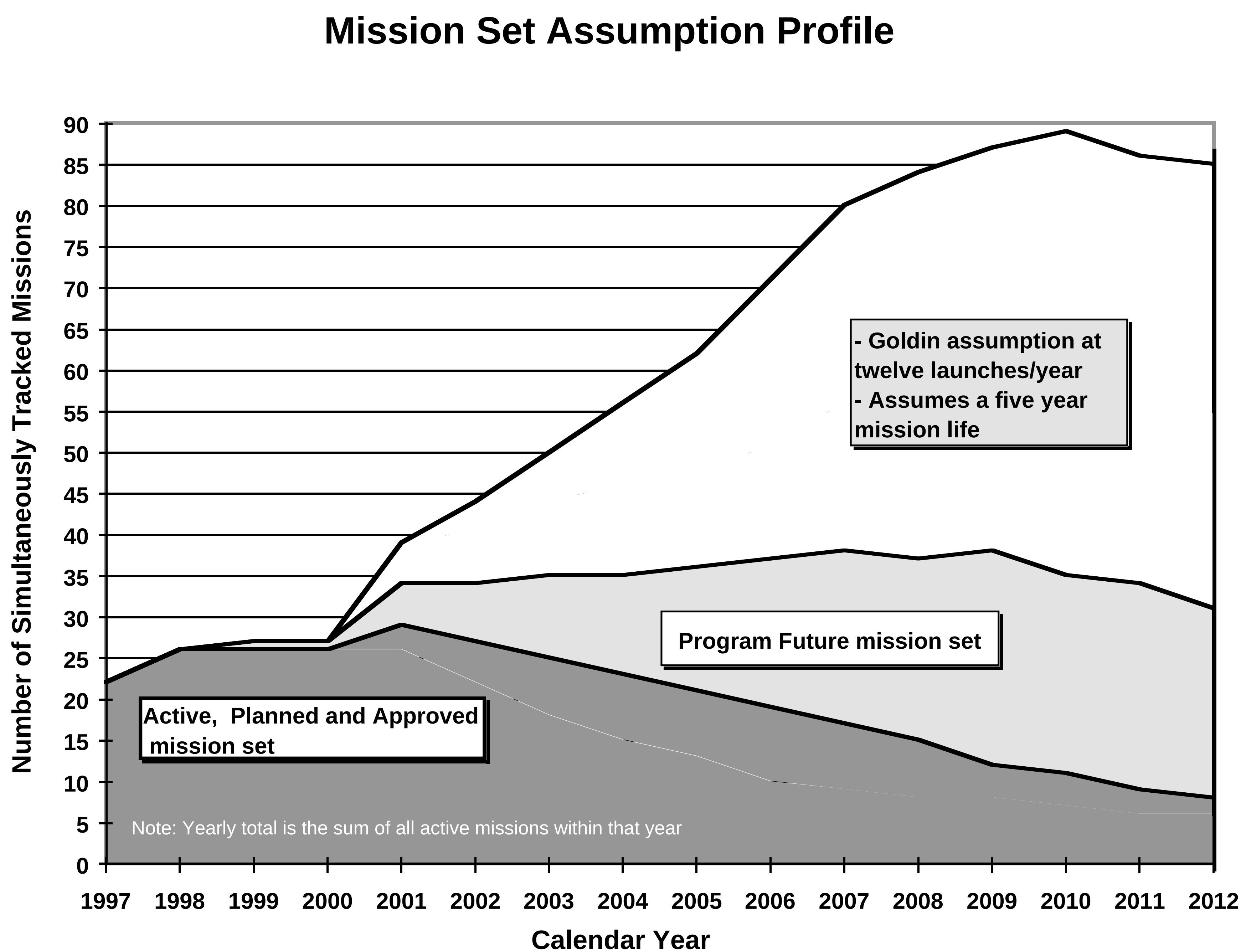
Introduction

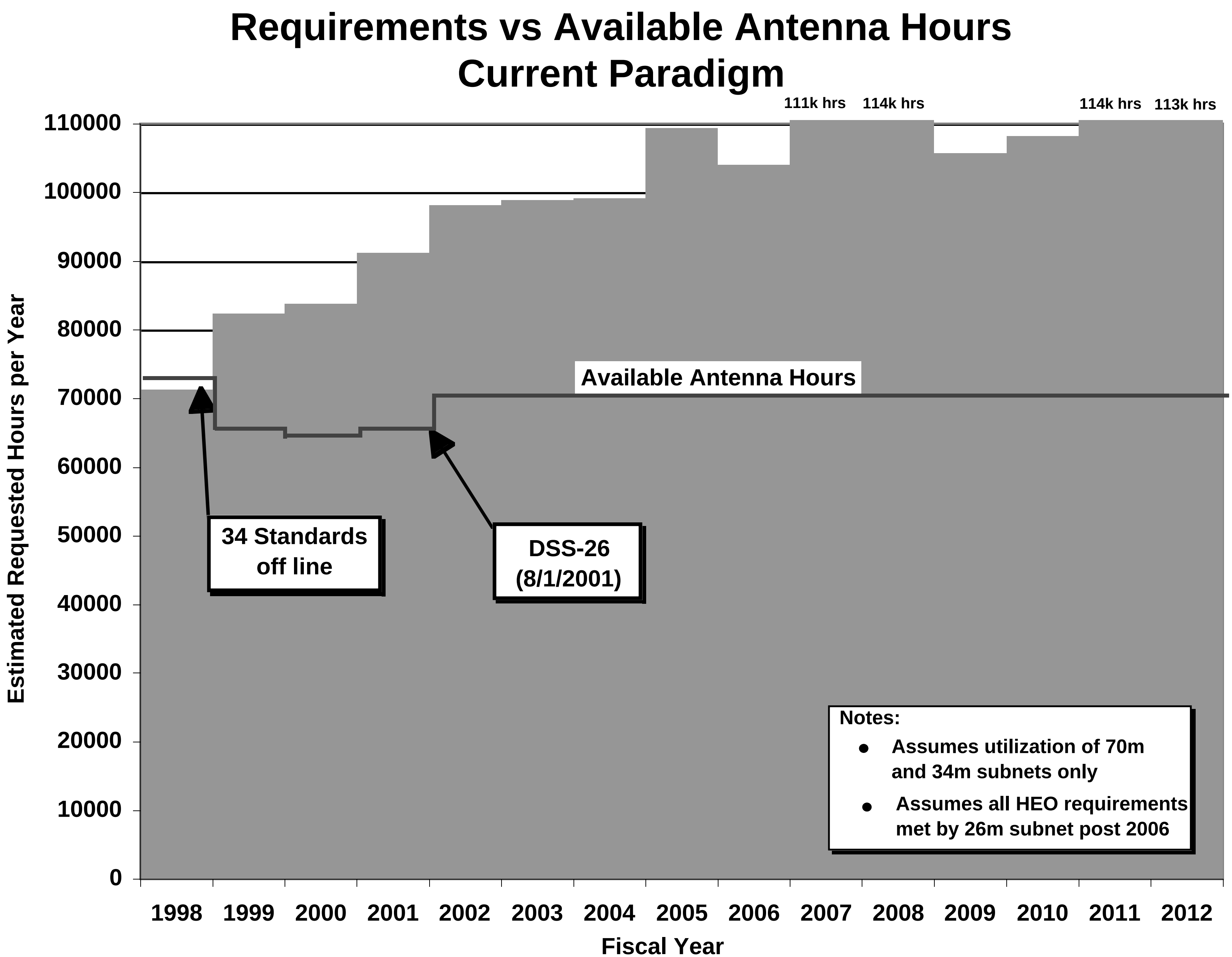
- **NASA's Strategic Plan calls for "establishing a virtual presence throughout the solar system"**
- **The capabilities of NASA's deep space communications systems will be a key factor in the fidelity of this virtual presence**



Deep Space Telecommunications Challenges

- **Much more frequent launches**
  - **Conservative SOMO/OSS mission set assumptions includes 4-6 launches per year**
  - **Goldin has challenged NASA to strive towards one deep space launch per month**
- **Significant increase in number of simultaneous missions**
  - **Conservative SOMO/OSS mission set shows mission load increasing from current level of about 25 to about 35 simultaneous missions**
  - **Baseline loading analysis, using current telecom technology and approach, results in 60% oversubscription of ground network**
- **Outer planet missions**
  - **R^2 scaling implies that communication from Neptune, and Pluto is more than 100 times more difficult than Mars-Earth links *(and more than 10 billion times harder than GEO comm links!)***
- **High-resolution multispectral instruments, orbital and *in situ* investigations, demand increased telemetry bandwidth**
  - **Communications bandwidth will impost ultimate limit on science mapping resolution for many missions**


Mission Set Assessment Profile
Number of Simultaneously Tracked Missions
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
- Goldin assumption at twelve launches/year
- Assumes a five year mission life
Program Future mission set
Active, Planned and Approved mission set
Note: Yearly total is the sum of all active missions within that year
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Calendar Year


Requirements vs Available Antenna Hours
Current Paradigm
111k hrs
114k hrs
114k hrs
113k hrs
110000
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Estimated Requested Hours per Year
Available Antenna Hours
34 Standards off line
DSS-26 (8/1/2001)
Notes:
Assumes utilization of 70m and 34m subnets only
Assumes all HEO requirements met by 26m subnet post 2006
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Fiscal Year

Baseline Loading Assumptions

Current Day Paradigm

- **Assumes current network technology level, current**
  - **Three 8-hr tracks per week in cruise**
  - **One 10-hr track per day in prime phase**

Detailed Assumptions:

- Future Mission Set
  - Cruise support assumed to be three 8 hour tracks/week
  - Prime mission support at seven 10 hour tracks per week (average)
  - Pre- and post- calibrations worst case at 1.5 hrs (assume prime and extended phase have same requirements)
  - Launch support assumed to be continuous for 30 days @ 850 hours
- Baseline Mission Set
  - Currently planned missions in Resource Allocation Baseline mission set - remain unchanged
- Exceptions
  - Cooperative and non NASA mission support the same as NASA missions
  - MED program assumptions:
    - Mars missions supported by MSPA
    - Mars landers supported by relay operations
    - Mars relay operates at 14 hrs/day
  - SESPD Program assumptions:
    - Europa Orbiter supported at 14 hrs/day

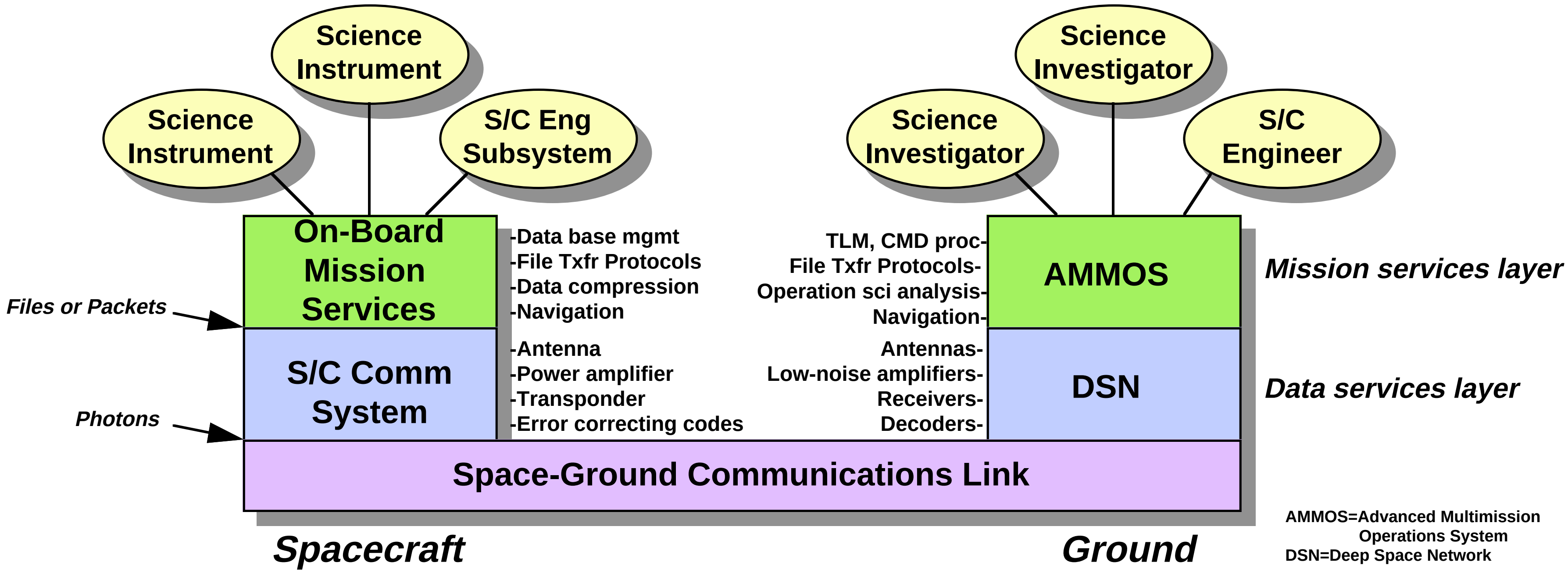
NASA's Telecommunications Strategy

How will NASA respond to this challenge?

- **Establish an integrated flight-ground architecture**
- **Transition to a new service-oriented paradigm**
- **Rapidly infuse new technology (flight *and* ground)**

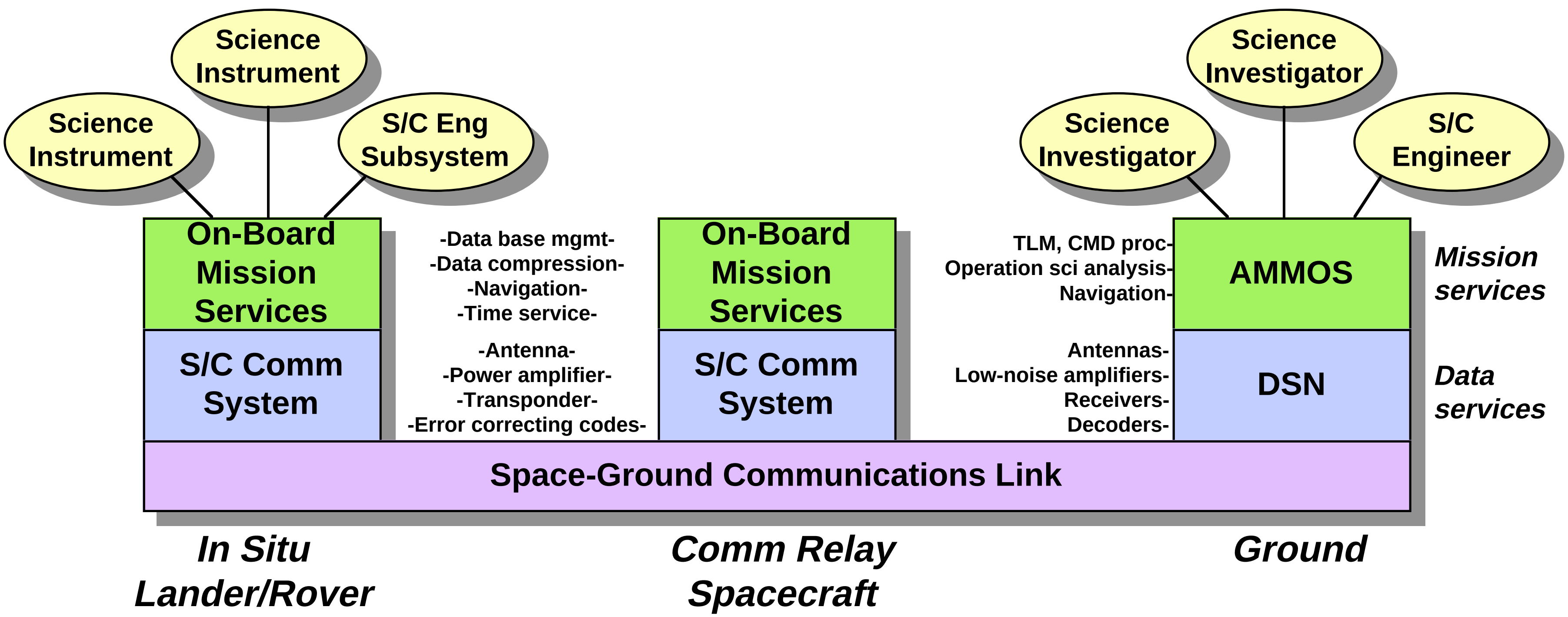
Integrated Flight-Ground Architecture

- **TMOD will deliver integrated flight-ground telecommunications and data management systems and services**
  - **Enabling process for low-cost, rapid cycle-time missions**
  - **Also enables reduced TMOD costs by providing standard flight-ground interfaces**
  - **This integrated architecture is being defined in partnership with X2000**



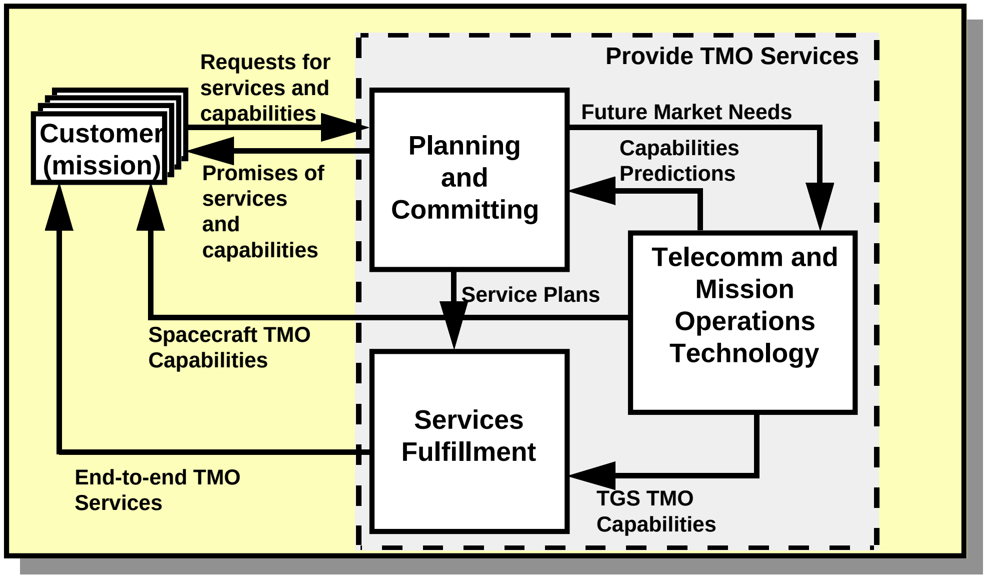
Integrated Flight-Ground Architecture (cont'd)

- **This network architecture extends naturally to include landers, communications relay orbiters, etc.**
- **Ultimate goal is a "Solar System Wide Area Network" that connects a scientist to his/her planetary robotic science payload**



TMOD's Services Paradigm

- **Service paradigm provides new perspective on telecommunications**
  - **TMOD supplies *standard* telemetry and command services**
    - **Goal is lower cost support of mission *set***
    - **Cost of adding unique, non-standard capabilities borne by mission**
  - ***Quantity*, *quality,* and *cost* of telecom services defined by flight/ground telecommunications technology**
  - **Need to match overall quantity of service to aggregate demand of mission *set***
  - **Technology advances will provide opportunities for cost-effective increases in service quality/quantity**



Technology Infusion

- **New technology will be key to cost-effectively meeting NASA's deep space telecommunications challenges**
- **In particular, two new technologies will enable large increases in NASA's deep space communications bandwidth**
  - **Ka-band communications**
  - **Optical communications**
- **This increased bandwidth will allow**
  - **Increased data return**
  - **Reduced tracking time**
- **Benefiting from these technologies requires coordination of flight and ground technology developments**

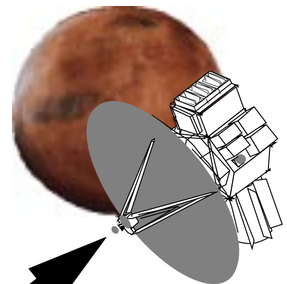
First, Some Key Metrics

- **Available antenna hours**
  - **Simply a function of number of antennas and utilization efficiency**
- **Data volume per pass**
  - **Normalize data rate to a reference spacecraft at Jupiter**
    - **RF: 1-meter effective antenna aperture, 10-Watt transmitted RF power for S, X, or Ka-band**
    - **Optical: 30-cm, 3-Watt transmitted laser power**
  - **Quantify data volume into an individual ground asset**
    - **34m, 70m antenna at RF**
    - **10m photon bucket at optical**
- **Overall DSN Capacity**
  - **Aggregate downlink communications rate of entire ground network**
    - **Combined data rates at each antenna supporting an ensemble of reference spacecraft at Jupiter distances**
      - **Current DSN capacity, in terms of this metric:**

S	***X***	***Ka***	***Optical***
20 kbps	*239 kbps*	*0 kbps*	*0 kbps*

RF Communications

- **New technologies will significantly increase the capacity of the existing Deep Space Network**



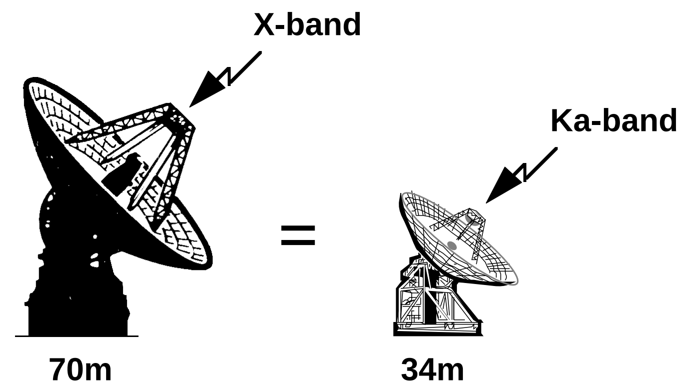
- **Spacecraft Transponding Modem**
  - **Supports new Turbo codes**
  - **X/Ka-band**
  - **Reduced mass/power/ volume/cost**
- **Ka-band power amplifiers**
- **X/Ka antennas**
- **Data compression**
- **Onboard storage**

- **Space link protocols (with re-transmission)**
- **Turbo codes**

- **Increased ground system automation (decreased pre/post-cal times)**
- **New cryogenic feed systems for improved SNR**
- **Ka-band ground stations**

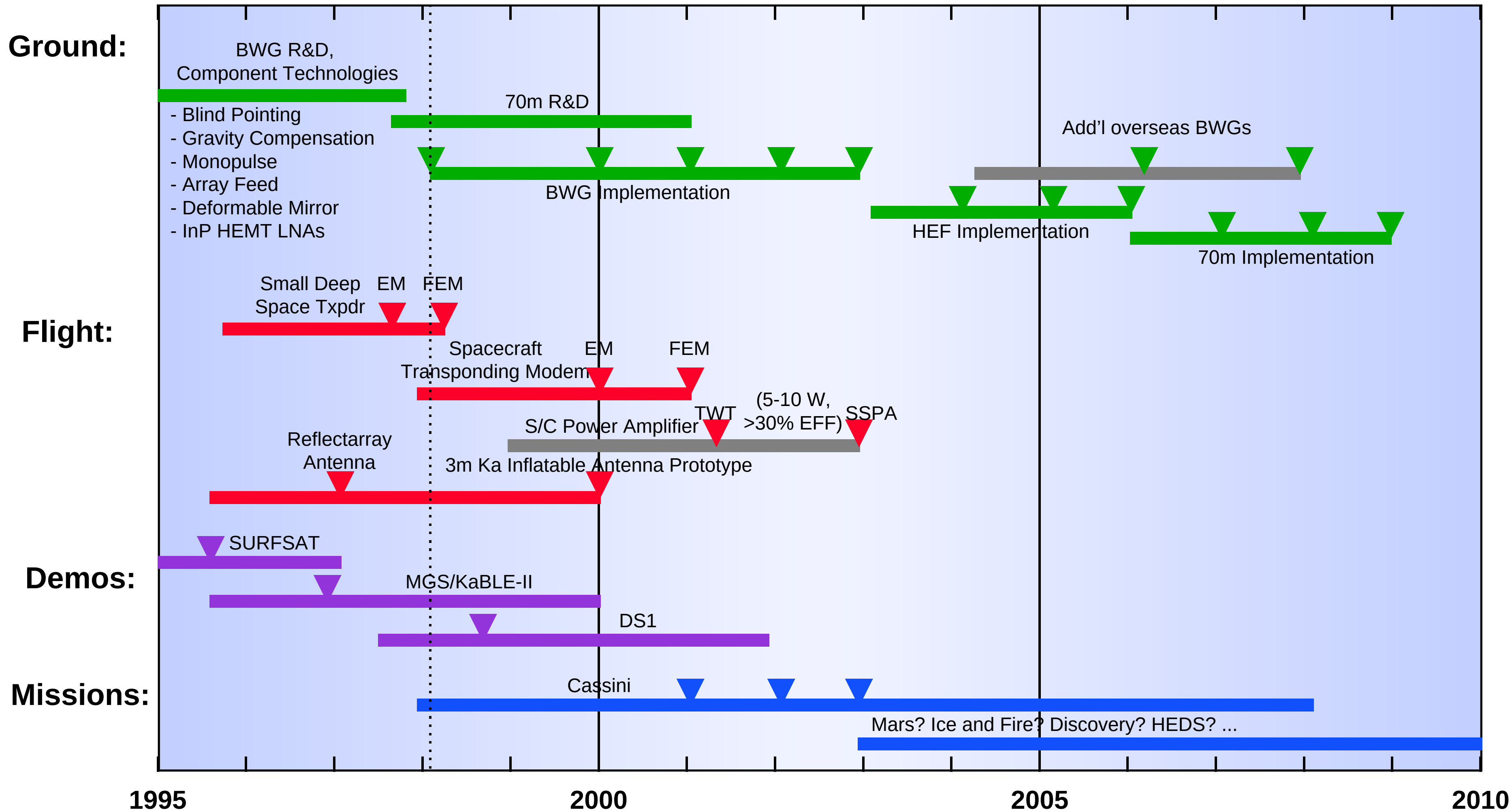
JPL

Ka-band Benefits



- **Ka-band offers ~6dB performance advantage over X-band for high-rate telecommunications**
- **How can this link advantage be used?**
  - **Cost-effective path to increase aggregate DSN capacity without building new antennas**
  - **Opens up new trade-space for future mission designers:**
    - **Missions can achieve 6 dB increase in data return (for a given s/c antenna diameter and DC power), or...**
    - **Mission can reduce contact times by a factor of 4, or...**
    - **Missions can obtain 70m/X-band level of performance from 34m/Ka-band, or...**
    - **Missions can maintain data rate while reducing spacecraft antenna area by factor of 4, or...**
    - **Missions can maintain data rate while reducing spacecraft transmitted power by factor of 4**
- **For this analysis, we assume missions will cut contact time in half while doubling their data return**

Ka-band Roadmap



Ka-Band Roadmap (Cont'd)

- **Addition of Ka-band to existing network is extremely cost-effective method to address increasing mission load and desire for increased bandwidth**
  - **Ka-band technology for 34m BWG well-understood based on demonstrations at DSS 13**
  - **34m HEF antennas should also support Ka-band**
    - **New panels required**
    - **New X/X/Ka-band tracking feed required**
    - **Structural stiffening required**
  - **TMO Technology Program is currently examining feasibility of adding Ka-band to 70m subnet**
    - **Huge potential added capacity**
    - **Gravity compensation to be achieved using deformable mirror and/or array feed**

DSS 13 R&D BWG Antenna

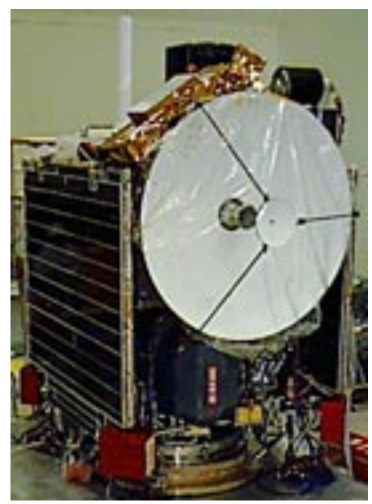
Ka-band Deformable Mirror

Ka-Band Roadmap (Cont'd)

- **Roadmap includes addition of second BWG antennas at Canberra and Madrid in latter part of next decade**
  - **Supports future HEDS missions**
    - **HEDS is currently examining use of 37/40 GHz band for piloted Mars missions**
    - **BWG antennas provide ideal facility for flexible implementation and operation of these additional frequency bands**
    - **HEDS missions will likely require robust, high-bandwidth, near-continuous coverage**
  - **Provides flexible arraying options at each complex**
    - **Continuity of telemetry rate capability between 34m and 70m**
    - **Robust backup in the event of 70m failure**
  - **Decision to build these antennas will be deferred until we have better understanding of:**
    - **HEDS requirements**
    - **Long-term 70m subnet sustaining costs**
  - **Costs for additional BWG antennas are $34.7M per aperture, including X-band and Ka-band electronics**

Ka-Band Roadmap (Cont'd)

- **Critical path items**
  - **Accelerated implementation of Ka-band on existing 34m BWGs**
  - **Development of improved Ka-band spacecraft transmitters**
    - **SOMO funding for this task ($1.5M) lost in recent budget cut**
  - **Demonstration and characterization of 70m Ka-band performance**
    - **Choice between deformable mirror/monopusle feed or array feed techniques for 70m pointing and gravity compensation**
    - **Successful 70m demo may argue for implementing Ka-band on 70m subnet before HEFs**
  - **Demonstrations and first operational experience**
    - **MGS**
    - **DS1**
    - **Cassini**

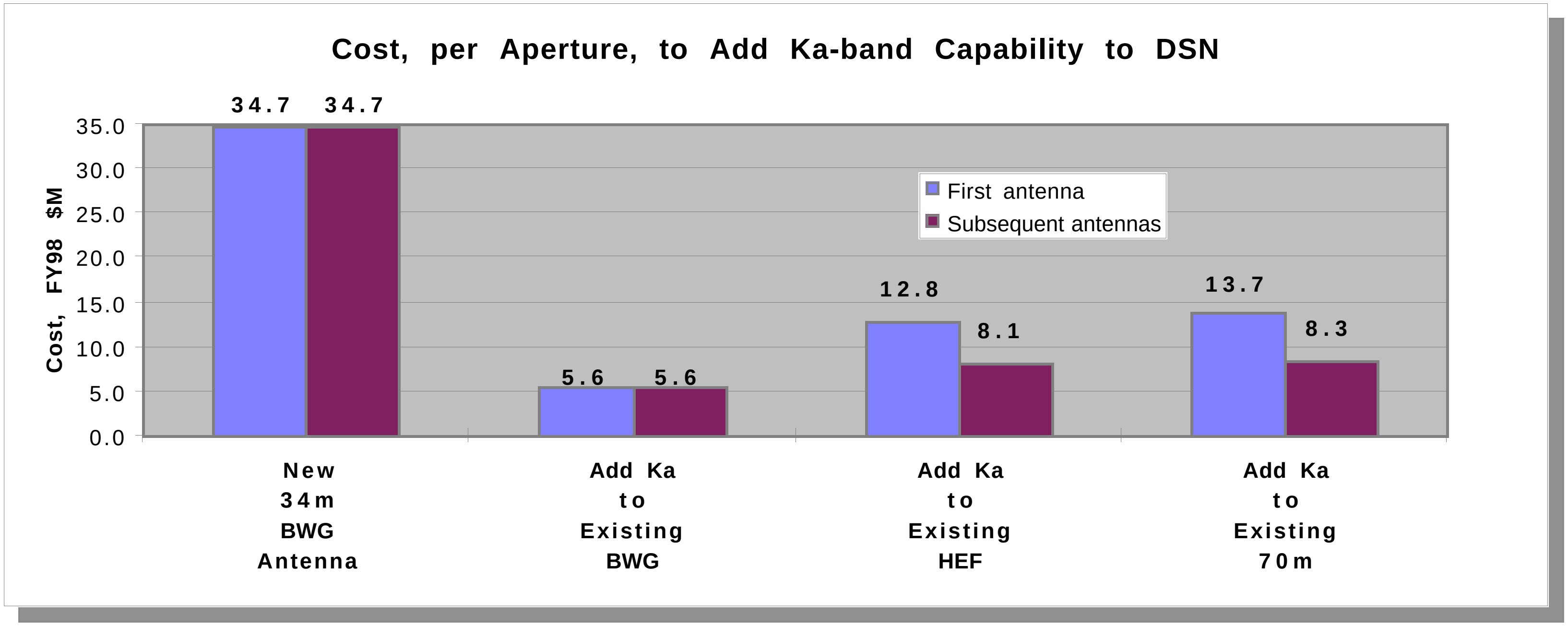


Mars Global Surveyor with Ka-Band Link Experiment

JPL

Ka-band Implementation Costs

- **Quick-look cost estimates have been made for adding Ka-band capability in the DSN**
  - **Assumptions:**
    - **X-up, X/Ka-down**
    - **Low-cost HEMT low-noise amplifiers**
    - **All Ka-band systems include monopulse tracking feed**
    - **X-band feeds upgraded when adding Ka to existing antennas**
    - **HEF and 70m configurations use new X/X/Ka feed**
    - **70m configuration uses deformable mirror to compensate for primary antenna surface distortions**



Impact of New Technology on Mission Load

- **Re-examine mission load based on technology benefits**
  - **Reduce pre/post cal times w/ network automation**
  - **Reduce tracking time (~factor of 2) based on coding, Ka-band**
    - **Still offers ~factor of 2 increase in data volume returned**

Detailed assumptions:

1. Reduced pre- and post- calibrations from 1.5 hrs to 30 min starting in 2003. (New missions only)
2. Missions launching in 2005 and beyond start implementing Ka band link strategy
   · One 5 hr track per week in cruise
   · One 5 hr track per day in prime phase
   (assume prime and extended phase have same requirements)
3. Reduce launch support for Ka band missions (330 hrs for 30 days)

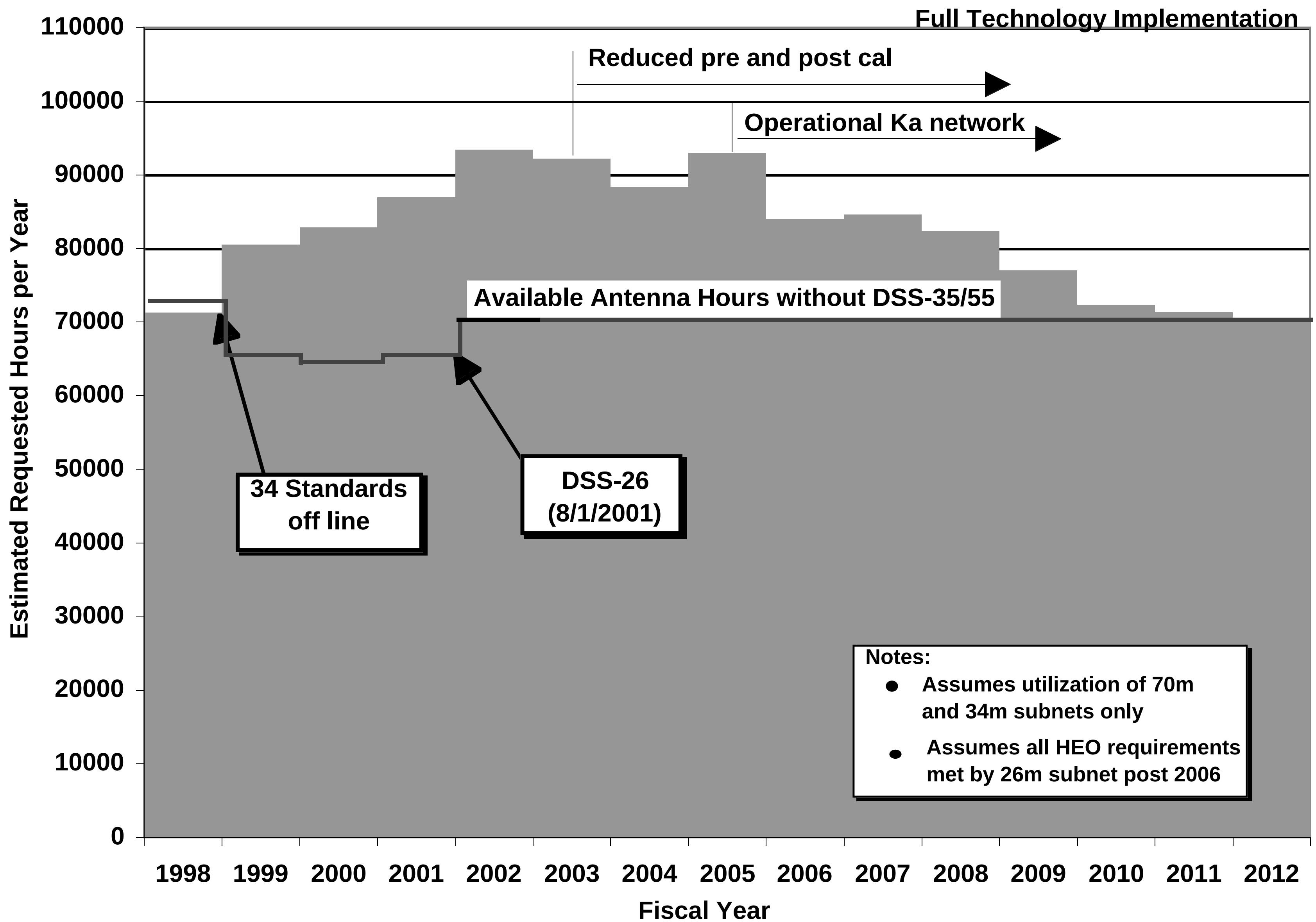
Old mission - those in the RAP baseline - remain as is

Cooperative missions require the following:
· One 8 hr track per week in cruise
· On 8 hr track per day in prime phase.

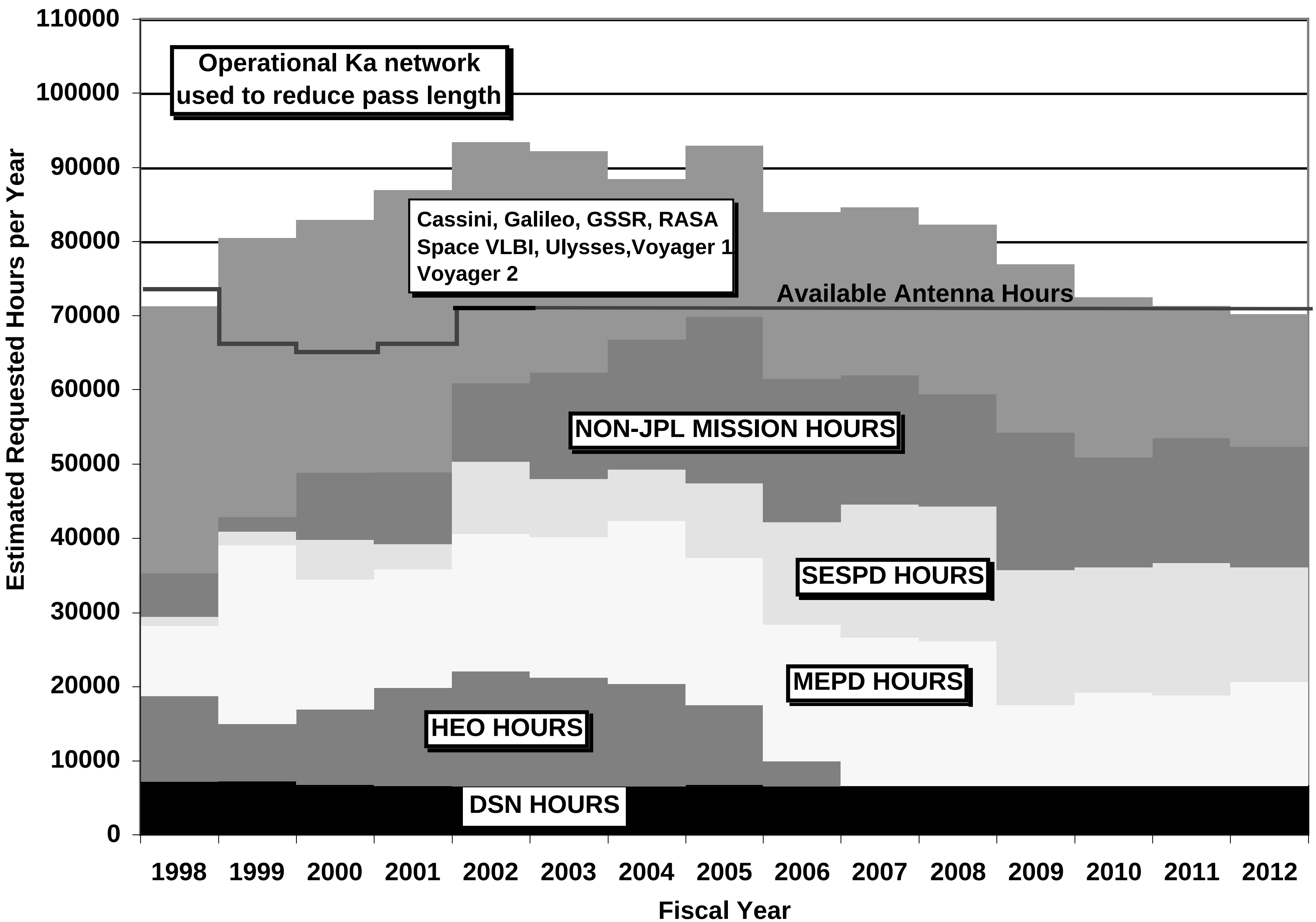
MED program assumptions
1. Mars missions supported by MSPA
2. Mars landers supported by relay operations
3. Mars relay operates at 10 hrs/day

SESPD Program assumptions
1. Europa Orbiter supported at 10 hrs/day

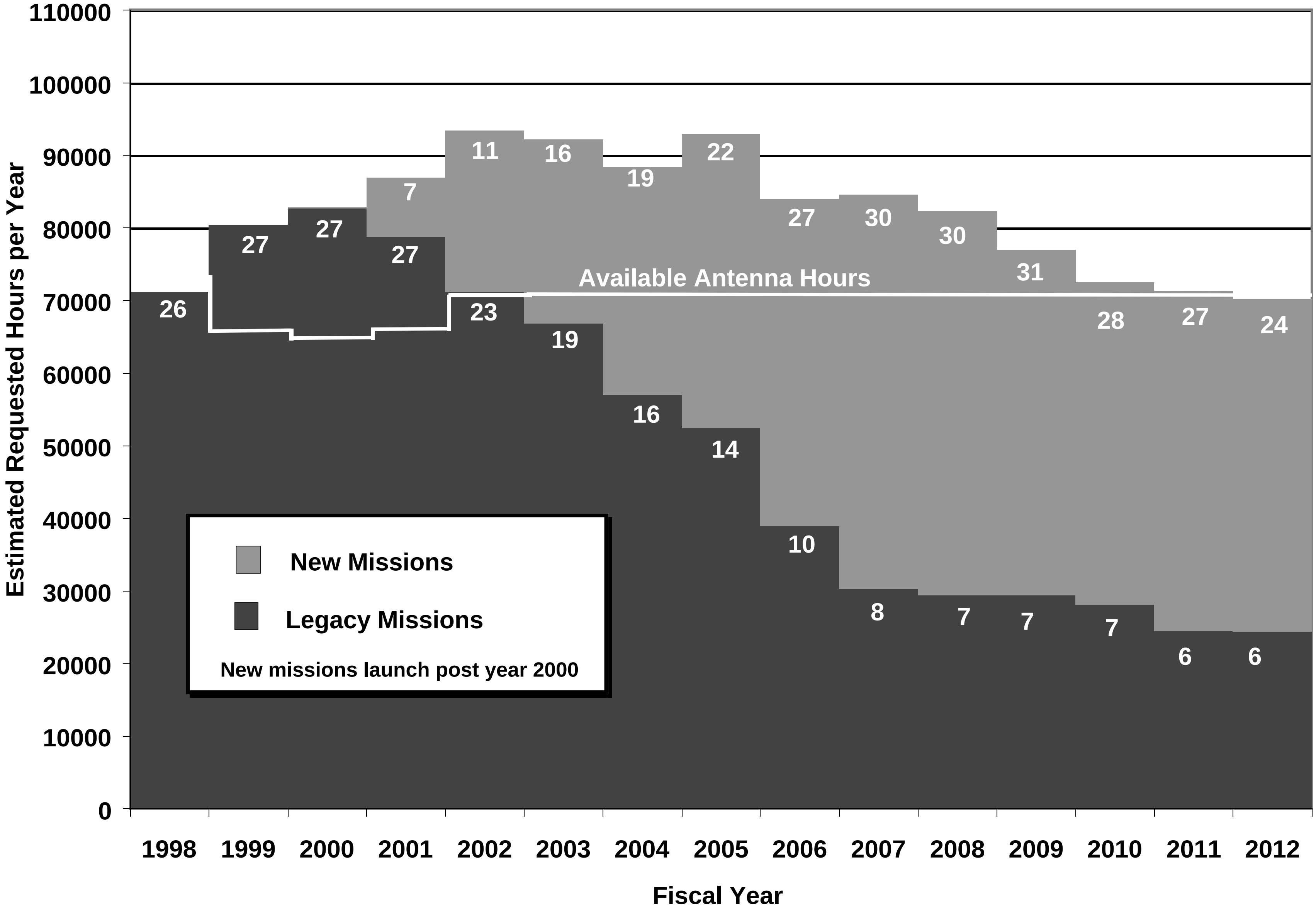
Requirements vs Available Antenna Hours With Technology Implementation

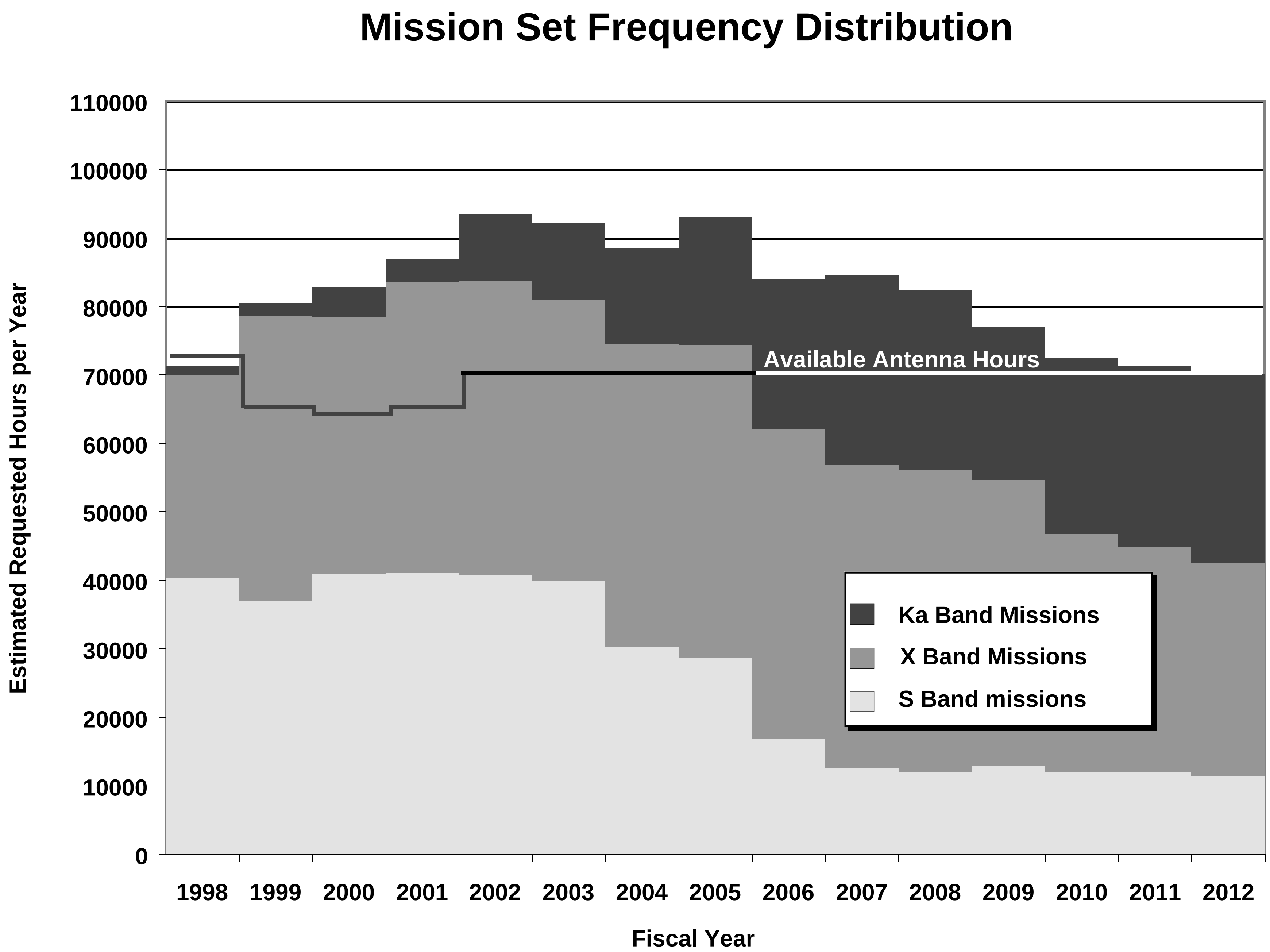


Total Hours by Program Classification

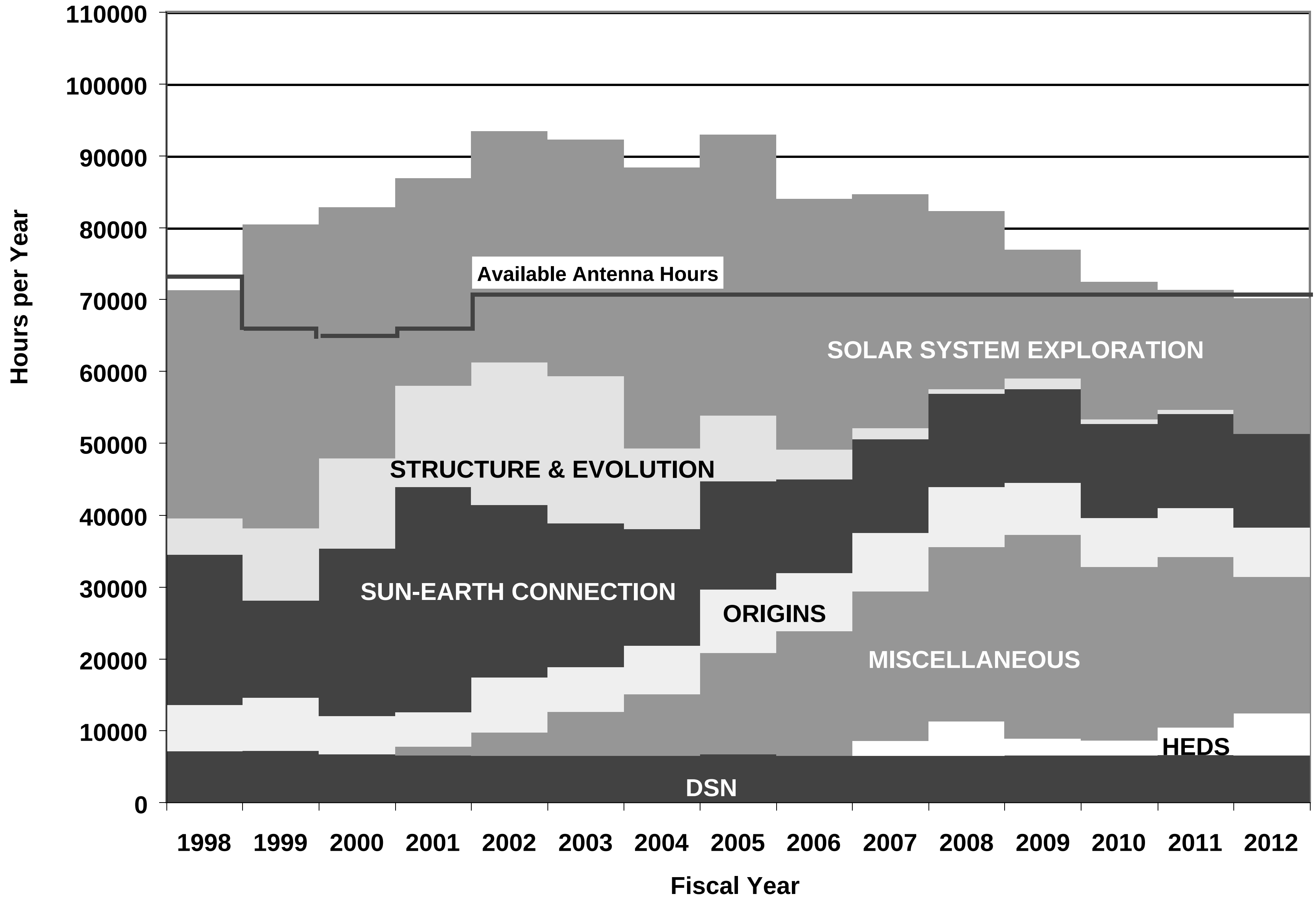


Legacy and New Missions




Mission Set Frequency Distribution
110000
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Estimated Requested Hours per Year
Available Antenna Hours
Ka Band Missions
X Band Missions
S Band missions
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Fiscal Year

Distribution by Code S Program Thrusts



Optical Communications

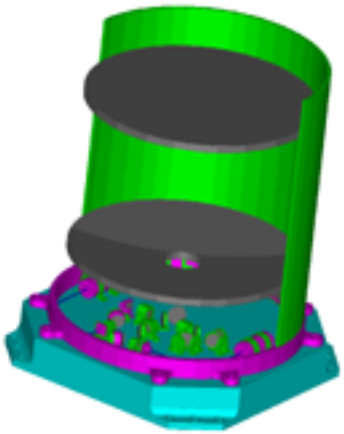
- **Optical communications offers an entirely new approach to communications**
  - **Higher data rates due to highly directive laser signal**
  - **Reduction in size, mass, power of spacecraft telecom system**
  - **Integration of telecom with multispectral imager, nav camera, lidar receiver**
- **NASA is committed to aggressively apply new technology to its future missions**
  - **Take the lead in the development of this technology, which will also have important benefits for Earth orbiting science and commercial communications satellites**
- **Optical communications is right at the beginning of its growth curve**
  - **Component-level technology development is expected to lead to significant future growth in optical comm capability**

Current Status

- **Important initial technology steps have been taken**
  - **Optical Communications Demonstrator (TAP/Code X,S)**
  - **GOPEX (Galileo) and GOLD (ETS-VI) demonstrations (TMOD/Code O,SOMO)**

Optical Comm Demonstrator
- 10 cm telescope
- Fiber-coupled laser

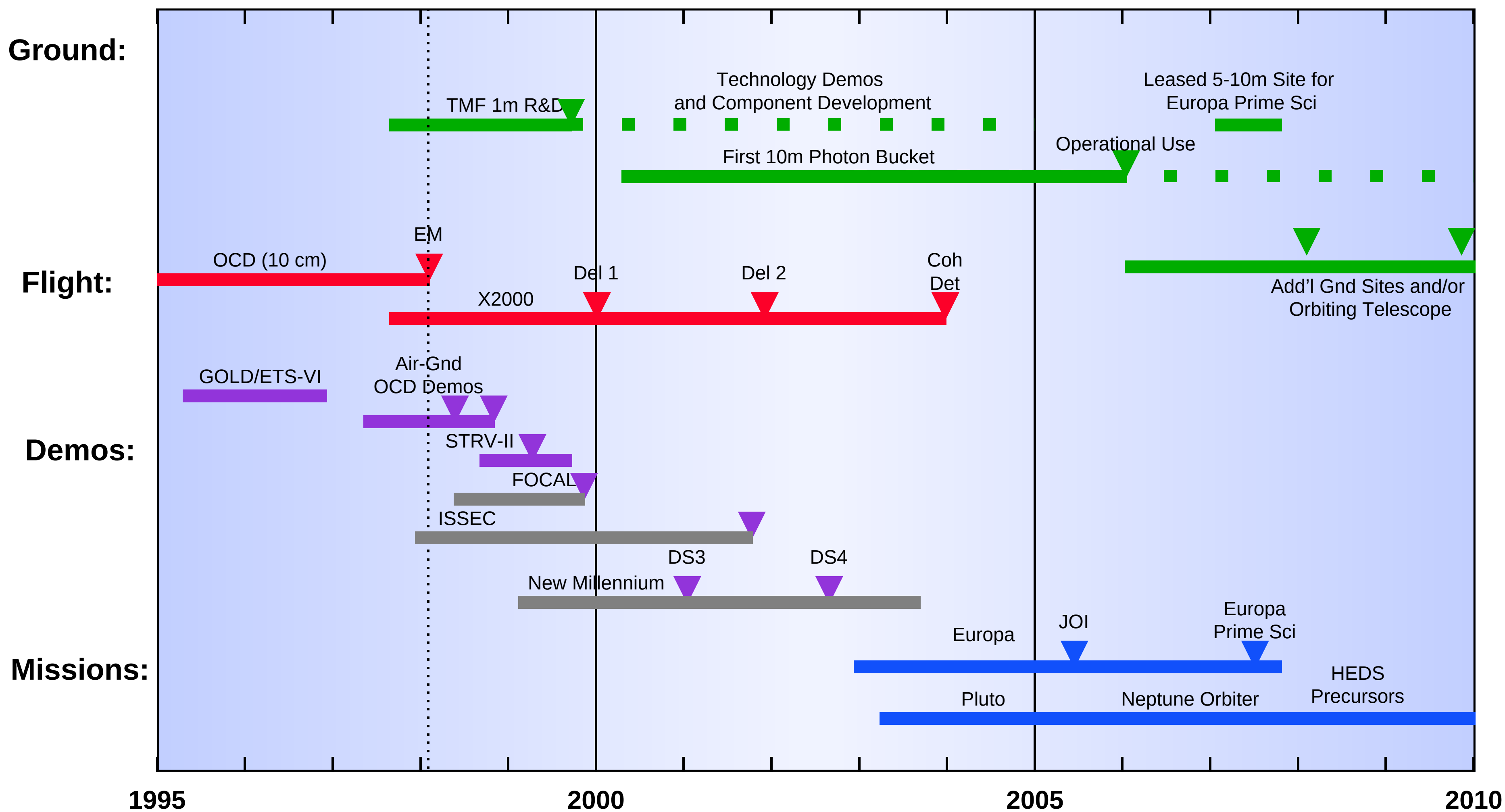
GOLD/ETS-VI Demo
Table Mtn Facility



Preliminary Layout for X2000 Optical Comm Transceiver
- 30 cm telescope
- 3W laser output

- **X2000 program is investing in flight transceiver EM**
  - **Targeted for Ice & Fire missions**
    - **Europa Orbiter**
    - **Pluto Express**
  - **Complementary ground development is required to capitalize on this investment**

Optical Roadmap



Optical Roadmap

- **1-meter R&D site**
  - **Early development of 1m R&D telescope crucial to support near-term flight demonstrations as well as technology development for ultimate operational capability**
- **Flight Demonstrations**
  - **Critical gap in current roadmap is lack of committed flight demonstrations of the current OCD or the planned X2000 optical comm terminals**
  - **Need to establish meaningful near-term flight demonstration on one of the following platforms:**
    - **STS (FOCAS proposal)**
    - **ISS (ISSEC proposal)**
    - **New Millennium (DS3, DS4, EOx)**

Optical Roadmap (cont'd)

- **Operational sites**
  - **10m photon bucket (non-diffraction-limited optics) for downlink**
  - **1m uplink telescope with high-power laser**
- **Europa Orbiter**
  - **Current target for first science user**
  - **Project is evaluating optical communications option for enhanced science return**
    - **Mission will fly RF system for baseline comm needs; optical comm would be added to augment downlink capability**
    - **Oct'99: Europa decision date on optical comm (project needs to see a committed plan for building needed ground capability at this point)**
    - **Jul'02 earliest possible launch date**
    - **Cruise checkout of optical comm package will be supported by 1m R&D station**
    - **Baseline plan for support of short prime science phase (Jul-Oct'07)**
      - **First operational DSN 10m (comes on-line '06)**
      - **"Borrowed" 2nd 10m station (TMOD supplied electronics at leased site)**

Optical Roadmap (cont'd)

- **HEDS applications**
  - **HEDS is interested in demonstrating optical comm on robotic Mars missions to evaluate technology for HEDS applications**
- **Critical path items**
  - **1m R&D site**
    - **SOMO funding for this taks ($3.5M) lost in recent budget cut**
    - **FY98 start critical for support of near-term demonstrations**
  - **10m operational site**
    - **FY00 CofF commitment required for Europa prime science readiness date**
  - **Clarificiation of and commitment for near-term demonstrations**
    - **STS/ISS**
    - **New Millennium EOx, DS3, DS4**

Optical Implementation Costs

- **Preliminary costing of a first operational optical communications ground station has been completed**
  - **Assumptions:**
    - **10m "photon bucket" receive aperture, non-diffraction-limited surface accuracy**
    - **1m uplink telescope**
    - **Includes adaptive optics for uplinks to outer planet missions**
  - **Total cost is $42M in FY98 dollars**
    - **As a benchmark, the Keck telescope (w/ better surface resolution) cost $94M**

JPL

Data Return per Tracking Pass

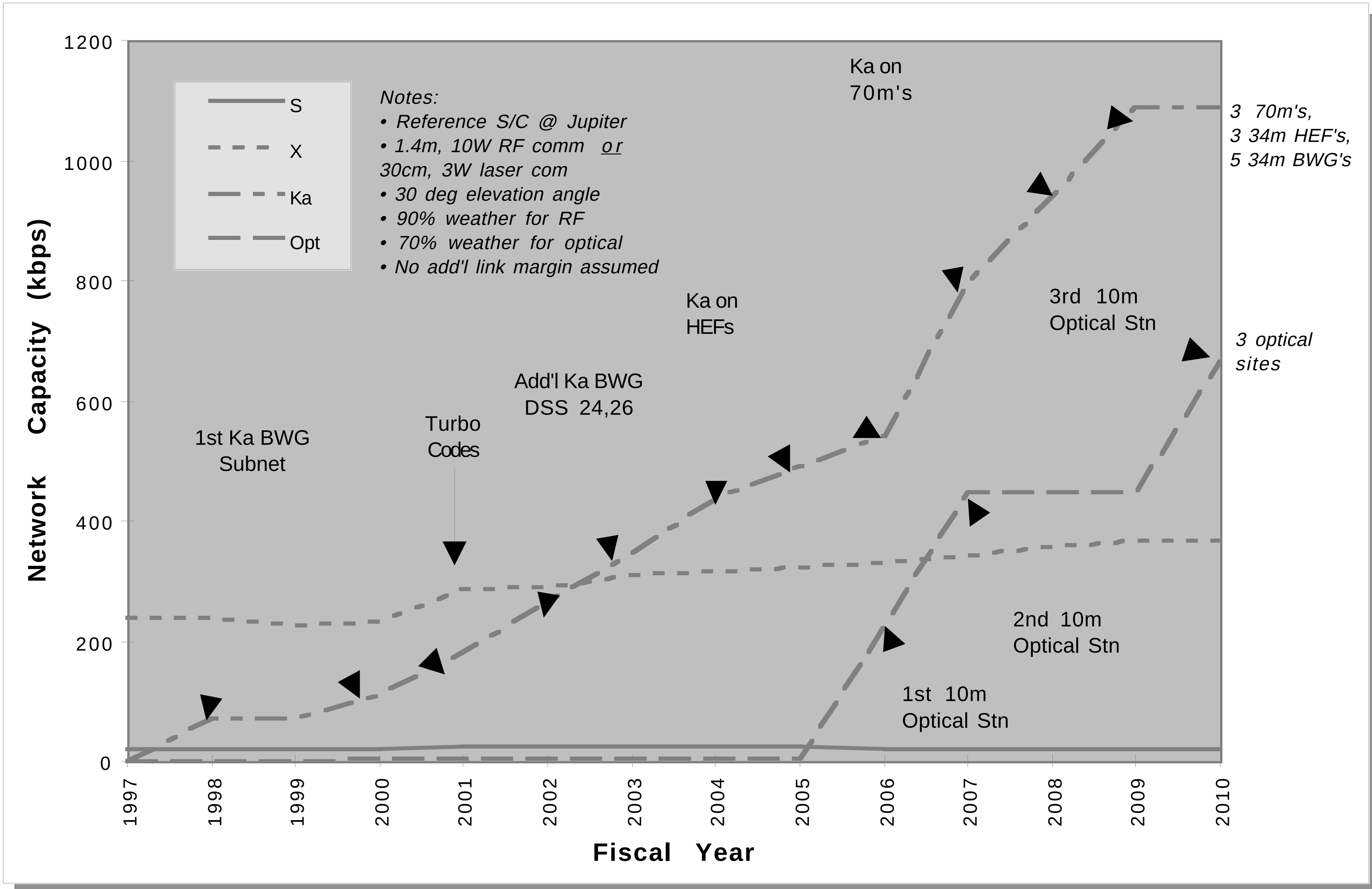
- **Ka-band and optical offer potential for significant increase in data volume return in a short (5-hour) pass**
  - **Ka-band offers ~ fourfold increase in returned data volume relative to X-band**
    - **34m/Ka-band ~ 70m/X-band**
  - **Optical offers highest average performance**
    - **However, there is significant variation with Sun-Earth-Probe angle**

Data Return (MBytes) for a 5-hour tracking pass

	X-band		*Ka-band*		*Optical*	
Planet	**34m**	**70m**	**34m**	**70m**	**1m**	**10m**
Mars	182.6	727.5	659.6	1772.1	29.5	2151.3
Jupiter	42.2	168.2	152.5	409.6	6.8	497.3
Saturn	12.5	49.9	45.2	121.4	2.0	147.4
Pluto	0.7	2.9	2.6	7.1	0.1	8.4

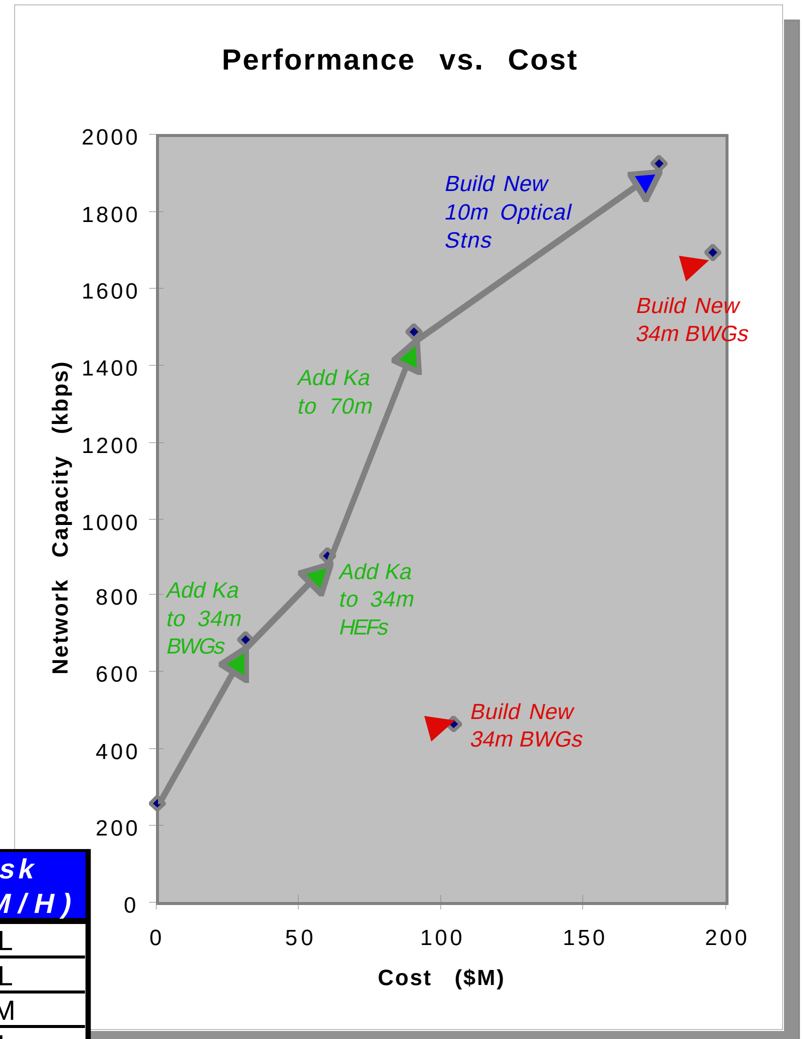
Notes:
RF cases referenced to 1m effective s/c antenna, 10 W RF radiated power
Optical cases referenced to 30 cm s/c telescope, 3 W optical transmitted power, λ =1.06 μ
RF values averaged over complexes; optical assumes Goldstone
RF cases assume 6K CCR HEMT LNA systems
Optical cases averaged over Sun-Earth-Probe (SEP) angle
Optical performance varies w/SEP angle; 10m: +-50% (1m: +-5%) for SEP=180 deg-10deg
All cases referenced to data rate at 30 deg elevation
RF links assume 90% availability; optical assumes 70%; data volume deweighted by availability
No additional link margin included

Evolution of Ground Network Capacity



Bang for the Buck

- **Which ground system investments provide the highest benefit/cost ratio?**
  - **Adding Ka-band to existing DSN assets is the most cost-effective near-term option**
    - **Leverages off value of current antennas**
  - **Once Ka-band is implemented on existing antennas, optical appears more cost-effective than adding additional RF antennas**



Caveats:

- Analysis only includes implementation costs
- Different levels of technology risk and technology readiness for the various options

	Bang (kbps)	Bucks ($M)	Bang/Buck (kbps/$M)	Risk (L/M/H)
Add Ka to Existing 34m BWGs	430	31.0	13.9	L
Add Ka to 34m HEFs	213	29.1	7.3	L
Add Ka to 70m	584	30.3	19.2	M
Add two new BWGs w/ X/Ka	141	69.5	2.0	L
Add 10m optical	221	42.9	5.1	H

Summary

- Most cost-effective approach to increasing network capacity for the coming decade is to convert existing DSN antennas to Ka-band
  - Order, based on technology readiness, would be
    - 34m BWG
    - 34m HEF
    - 70m
  - Need to incentivize move to Ka-band by clarifying data volume benefits and mandating reduced coverage in future AOs
- Optical communications provides longer-term growth path for deep space communications
  - High performance
  - Most cost-effective approach to increased bandwidth after adding Ka-band to existing DSN assets
  - Path to next-generation sciencecraft
  - Will provide technology spin-off for NASA LEO missions and for commercial communications

Recommendations

- **Rapidly infuse Ka-band capability into entire DSN**
  - **Will enable missions to obtain *increased* data volume with *reduced* tracking time**
  - **Apply autonomy and data compression to further enable maximum science return with reduced tracking**
  - **Key technology required**
    - **Higher efficiency spacecraft amplifiers**
    - **70m gravity compensation systems (deformable mirror or array feed)**
  - **Vigorously defend Ka-band spectrum allocation against potential RFI sources**
- **Estimated cost to add Ka-band to all existing DSN antennas:**

(Real-Year $M)	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10
Goldstone														
DSS 25	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DSS 24	0.0	0.0	0.0	3.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DSS 26	0.0	0.0	0.0	0.0	3.1	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DSS 15	0.0	0.0	0.0	0.0	0.0	7.2	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DSS 14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	8.7	0.0	0.0	0.0	0.0
Canberra														
DSS 34	0.0	2.8	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DSS 45	0.0	0.0	0.0	0.0	0.0	0.0	4.7	4.9	0.0	0.0	0.0	0.0	0.0	0.0
DSS 43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	5.4	0.0	0.0	0.0
Madrid														
DSS 54	0.0	0.0	2.9	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DSS 65	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9	5.0	0.0	0.0	0.0	0.0	0.0
DSS 63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	5.6	0.0	0.0
Total:	**2.7**	**2.8**	**5.8**	**5.9**	**6.1**	**10.4**	**12.1**	**9.7**	**13.4**	**14.0**	**10.8**	**5.6**	**0.0**	**0.0**

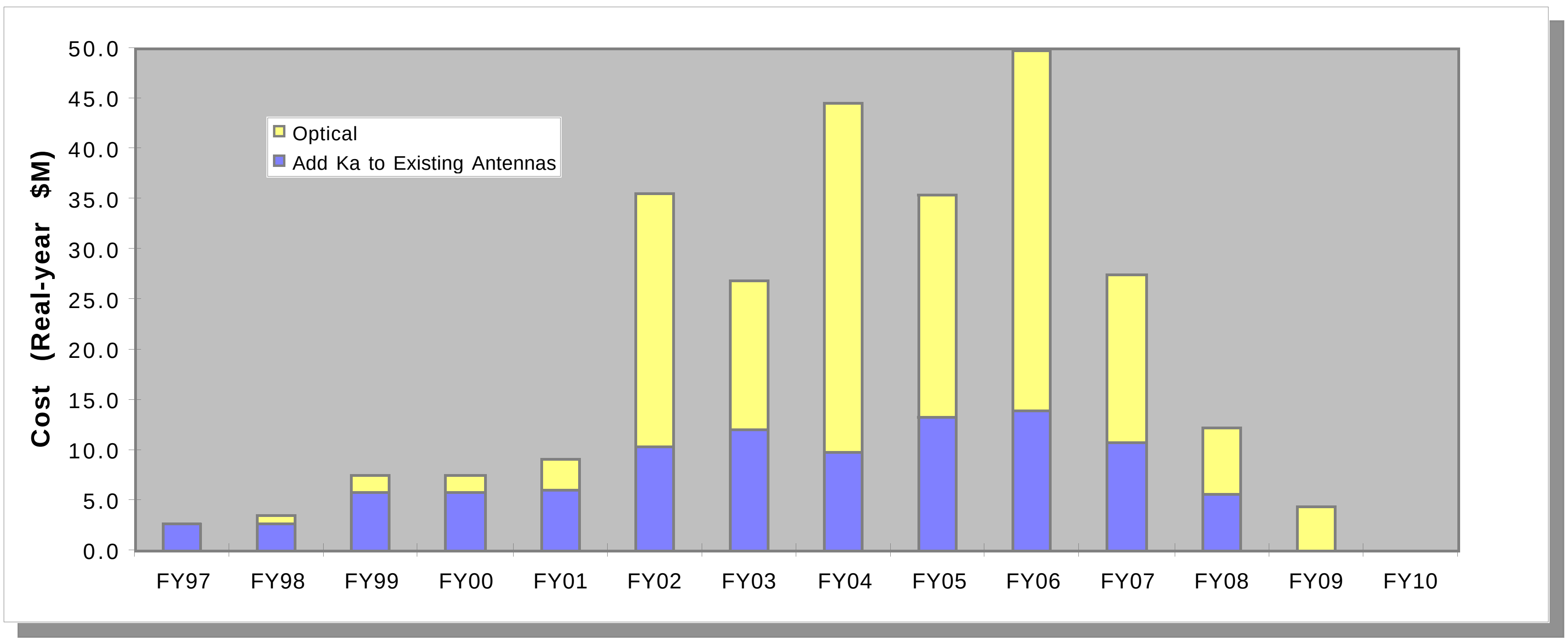
Recommendations (cont'd)

- **Continue to aggressively move forward in establishing an optical comm capability**
  - **Focus optical communications roadmap (and JPL resources) on a meaningful near-term flight demonstration, supported w/ 1m R&D site**
    - **Shuttle, Space Station?**
    - **New Millennium (DS3,4? EO_?)**
  - **Continue "technology push" of optical comm to Europa as mission enhancement**
  - **Align X2000 optical comm EM design with Ice & Fire mission operations concepts**
    - **Reconcile mission view of hybrid 2-way RF/downlink-only optical with X2000 2-way optical transceiver**
  - **Agree on operational optical ground network need dates after Ice & Fire mission sequence is established**
- **Funding profile for 1m R&D site, first 10m operational site, and second borrowed site, for '07 Europa encounter readiness date:**

(Real-Year $M)	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	Total
1m R&D Stn	0.7	1.8	0.3	0.1	0.0	0.0	0.0	0.0	0.0	**2.9**
First Operational 10m Stn	0.0	0.0	1.3	2.9	23.8	11.2	6.1	3.9	0.0	**49.2**
Borrowed Site for Europa	0.0	0.0	0.0	0.0	0.0	0.4	2.2	3.0	2.6	**8.2**
Total:	**0.7**	**1.8**	**1.6**	**3.0**	**23.8**	**11.5**	**8.3**	**6.9**	**2.6**	**60.3**

Cost Summary

(Real-Year $M)	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10
RF:													
Existing BWG Ants (5)	2.8	5.8	5.9	6.1	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEF Subnet (3)	0.0	0.0	0.0	0.0	7.2	12.1	9.7	5.0	0.0	0.0	0.0	0.0	0.0
70m Subnet (3)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	14.0	10.8	5.6	0.0	0.0
Add Ka to Existing Antennas	**2.8**	**5.8**	**5.9**	**6.1**	**10.4**	**12.1**	**9.7**	**13.4**	**14.0**	**10.8**	**5.6**	**0.0**	**0.0**
Optical:													
1m R&D Stn	0.7	1.8	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
First Operational 10m Stn	0.0	0.0	1.3	2.9	23.8	11.2	6.1	3.9	0.0	0.0	0.0	0.0	0.0
Borrowed Site for Europa	0.0	0.0	0.0	0.0	0.0	0.4	2.2	3.0	2.6	0.0	0.0	0.0	0.0
2nd, 3rd Operational 10m Stns	0.0	0.0	0.0	0.0	1.4	3.1	26.7	15.1	33.2	16.7	6.8	4.4	0.0
Optical	**0.7**	**1.8**	**1.6**	**3.0**	**25.2**	**14.6**	**35.0**	**22.1**	**35.8**	**16.7**	**6.8**	**4.4**	**0.0**



Funding Status

- **TMOD Engineering is re-working program plan to reduce ops costs and create an out-year funding wedge for network capacity investment**
  - **Network Simplification Program (NSP) will increase antenna availability and reduce operations costs**
- **Ka-band implementation through FY04 can largely be funded within existing TMOD budget except for phasing**

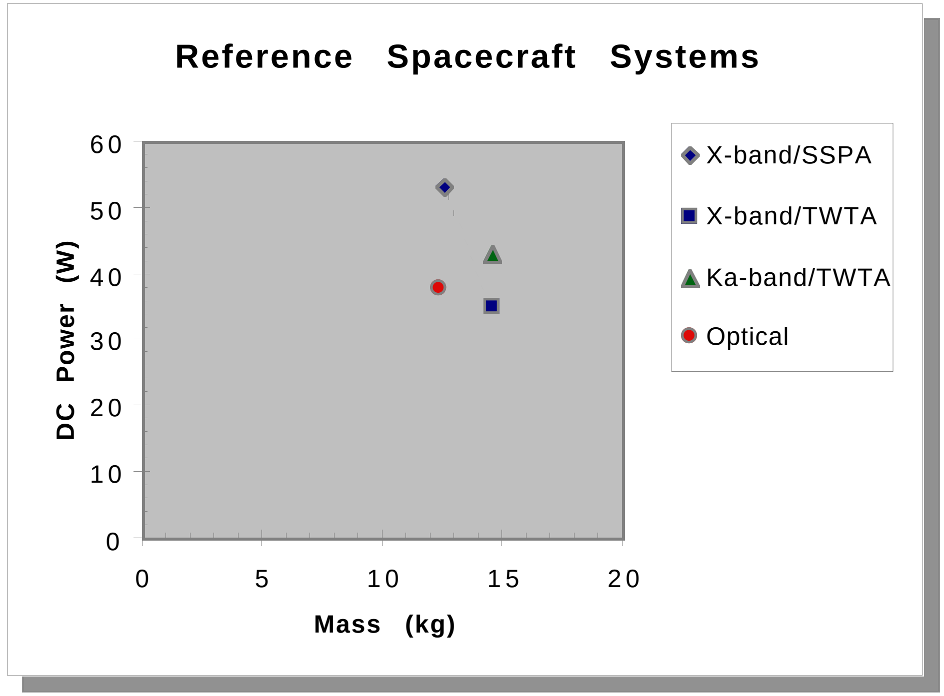
Funding (Real-yr $K)	FY98	FY99	FY00	FY01	FY02	FY03	FY04	TOTAL
AVAILABLE	**0**	**23**	**-4,345**	**-9,729**	**7,448**	**22,836**	**19,000**	**35,233**
NSP WEDGE SPREADSHEET	1,000	3,873	5,667	4,184	-12,121	-22,836	-19,000	-39,233
X/X DIPLEX FEED - 1 YEAR DELAY	0	-2,896	-3,322	3,545	2,673	0	0	0
DSS 27 EQUIPMENT	0	0	2,000	2,000	2,000			6,000
GENERAL SCRUB	-1,000	-1,000						-2,000
NEEDED FOR KA-BAND	**2,200**	**5,650**	**5,000**	**2,200**	**8,600**	**8,750**	**6,350**	**38,750**
PER ROAD MAP	2,800	5,800	5,900	6,100	10,400	12,100	9,700	52,800
CURRENTLY IN WAD	600	150	900	3,900	1,800	3,350	3,350	14,050
NEEDED FOR OPTICAL	**749**	**1,800**	**1,588**	**3,035**	**25,179**	**14,641**	**34,973**	**81,965**
KA SHORTFALL/EXCESS	**2,200**	**5,627**	**9,345**	**11,929**	**1,152**	**-14,086**	**-12,650**	**3,517**
TOTAL KA AND OPTICAL SHORTFALL	**2,949**	**7,427**	**10,933**	**14,964**	**26,331**	**555**	**22,323**	**85,482**
PROPOSED CODE M SOMO REDUCTIONS		**12,000**	**14,000**	**14,000**	**13,000**	**16,000**	**16,000**	**85,000**

Backup Slides

JPL

Reference Spacecraft Systems

- **Strawman telecom systems designs have been established for the X-band, Ka-band, and optical communications options**
  - **All systems provide full command, telemetry, and navigation functions**



	X-band (SSPA)	X-band (TWTA)	Ka-band (TWTA)		Optical
Mass	**12.5**	**14.5**	**14.5**	**Mass**	**12.3**
1.4 m ant	3.5	3.5	3.5	*Telescope*	7.4
Txpdr (dual)	1	1	1	*Elec Proc*	2.3
uWV and WG	5	5	5	*Laser Txmtr*	2.3
PA (dual)	3	5	5	*Misc*	0.3
Power	**53**	**35**	**43**	**Power**	**37.9**
Txpdr	10	10	10	*Telescope*	3.5
PA	43	25	33	*Elec Proc*	4.1
				Laser Txmtr	30.3

Analysis Mission Set

- **TMOD Missions**
  - Casini
  - Galileo
  - Goldstone Solar System RADAR
  - Radio Astronomy and Special Activities
  - Space VLBI
  - Ulysses
  - Voyager 1
  - Voyager 2
- **HEO MIssions**
  - ACE
  - AXAF
  - Imager for Magnetopause-to-Aurora GlobalExploration - IMAGE
  - Infrared Space Observatory - ISO
  - INTEGRAL
  - ISTP - CLUSTER II
  - ISTP - GEOTAIL
  - ISTP - POLAR
  - ISTP - SOHO
  - ISTP - WIND
  - Lunar Prospector
  - Microwave Anistropy Probe - MAP
  - MIDEX 3
- **Mars Missions**
  - Deep Space 2 - Mars microprobes
  - Aster 2001 Lander (Mars together candidate)
  - Aster 2001 Rover (Mars together candidate)
  - Mars Express 2003 Orbiter
  - Mars Express 2003 Lander
  - Deep Space 5 (Mars 2003 microseismometer)
  - Mars Surveyor 2007 Lander (w ISRU)
  - Mars 2007 Comm Obiter
  - Lunar Demo (HEDS)
  - Mars 09 Comm Orbiter (Areosync.)
  - Mars 2009 Sample Return
  - Mars 2009 Site Selection Lander
  - Mars 2011 Cargo mission
  - Mars Surveyor 2011 Obiter (Aerosync.)
  - Mars Surveyor 2001 Lander
  - Mars Surveyor 2001 Orbiter
  - Mars Surveyor 2003 Lander
  - Mars Surveyor 2003 Orbiter
  - Mar Surveyor 2005 Rover Sample Return
  - Mars Surveyor 1998 Lander
  - Mars Surveyor 1998 Orbiter
  - Mars Global Surveyor
  - Mars Pathfinder
  - Planet - B
- **SESPD Missions**
  - DISCOVERY 05
  - New Millennium Deep Space 3
  - DISCOVERY 07
  - CHAMPOLLION (NMP DS4)
  - SIM (OSI) Space Interferometry Mission
  - DISCOVERY 08
  - New Millennium Deep Space 6
  - New Millennium Deep Space 7
  - DISCOVERY 09
  - New Millennium Deep Space 8
  - MUTLI-PROBE JUPITER
  - EUROPA LANDER
  - NEPTUNE ORBITER
  - DISCOVERY 11
  - TITAN AEROBOT
  - DISCOVERY 12
  - IO ORBITER
  - New Millennium Deep Space 1
  - Europa Orbiter
  - Pluto Express
  - Solar Probe
  - Space Infrared Telescope
  - STARDUST
- **Non - JPL Missions**
  - DISCOVERY 06
  - ROSETTA
  - COOP 4
  - COOP 5
  - COOP 6
  - COOP 7
  - COOP 8
  - COOP 9
  - COOP 10
  - COOP 11
  - COOP 12
  - COOP 13
  - COOP 14
  - COOP 15
  - DISCOVERY 10
  - Gravity Probe B
  - International Cometrary Explorer
  - MUSES-C
  - NEAR
- **Deep Space Network**
  - DSN Calibration
  - DSS Maintainence

Analysis Mission Set Distribution

ASTRONOMICAL SEARCH for ORIGINS

MISSION NAME	MISSION ID	OSS	PROGRAM	PRGRAM REP	LAUNCH	EOPM	EOEM
Goldstone Solar System Radar	GSSR	ASO	RADIO ASTRONOMY	RIEGLER	04/01/85	04/01/20	04/01/20
Infrared Observatory	ISO	ASO	ISTP	RIEGLER	11/11/95	11/11/97	04/30/98
Radio Astronomy and Special Activities	RASA	ASO	RADIO ASTRONOMY	RIEGLER	04/01/85	04/01/20	04/01/20
SIM (OSI) Space Interferometry Mission	SIM	ASO	Origins Program	HOWARD	9/1/04	12/31/07	12/31/13
Space Infrared Telescope Facility	SRTF	ASO	ASTROPHYSICS	LAPIANA	12/01/01	01/31/07	- - -

DEEP SPACE NETWORK

MISSION NAME	MISSION ID	OSS	PROGRAM	PRGRAM REP	LAUNCH	EOPM	EOEM
DSN VLBI Clock Sync and Catalog M&E	DSN	DSN	NETWORK		04/01/85	04/01/20	- - -
DSS Maintenance	DSS	DSN	NETWORK		04/01/85	04/01/20	- - -

HUMAN EXPLORATION & DEVELOPMENT of SPACE

MISSION NAME	MISSION ID	OSS	PROGRAM	PRGRAM REP	LAUNCH	EOPM	EOEM
Lunar Demo	LDMO	M	HEDS		6/1/07	7/1/08	7/1/09
Mars 2009 Site Selection Lander	MSSL	M	HEDS		10/1/09	6/1/11	- - -
Mars 2011 Cargo mission	CAR1	M	HEDS		7/1/11	8/1/13	8/1/14
Mars 2014 Crewed mission	CRW1	M	HEDS		2/1/14	7/1/14	7/1/16
Mars Surveyor 2011 Obiter (Aerosync.)	M110	M	Mars Exploration Program		8/1/11	12/1/12	12/1/13

MISCELLANEOUS

MISSION NAME	MISSION ID	OSS	PROGRAM	PRGRAM REP	LAUNCH	EOPM	EOEM
COOP 04	COP4	MISC	COOP ESA/Europe/Russia		6/1/01	6/1/04	6/1/06
COOP 05	COP5	MISC	COOP Japan		7/1/02	7/1/05	7/1/07
COOP 06	COP6	MISC	COOP ESA/Europe/Russia		9/1/03	9/1/06	9/1/08
COOP 07	COP7	MISC	COOP Japan		11/1/04	11/1/07	11/1/09
COOP 08	COP8	MISC	COOP ESA/Europe/Russia		3/1/05	3/1/08	3/1/10
COOP 09	COP9	MISC	COOP Japan		8/1/06	8/1/09	8/1/11
COOP 10	COP10	MISC	COOP ESA/Europe/Russia		4/1/07	4/1/10	4/1/12
COOP 11	COP11	MISC	COOP MISSION		9/1/09	9/1/19	9/1/24
COOP 12	COP12	MISC	COOP MISSION		4/1/09	4/1/12	4/1/14
COOP 13	COP13	MISC	COOP MISSION		6/1/10	6/1/13	6/1/15
COOP 14	COP14	MISC	COOP MISSION		5/1/11	5/1/14	5/1/16
COOP 15	COP15	MISC	COOP MISSION		7/1/12	7/1/15	7/1/17
DISCOVERY 07	DM07	MISC	Discovery Candidate		12/1/03	12/1/06	12/1/08
DISCOVERY 08	DM08	MISC	Discovery Candidate		7/1/05	7/1/08	7/1/10
DISCOVERY 09	DM09	MISC	Discovery Candidate		10/1/06	10/1/09	10/1/11
DISCOVERY 10	DM10	MISC	Discovery Candidate		9/1/08	9/1/11	9/1/14
DISCOVERY 11	DM11	MISC	Discovery Candidate		8/1/10	12/1/13	12/1/15
DISCOVERY 12	DM12	MISC	Discovery Candidate		5/1/12	7/1/15	7/1/17
DISCOVERY 13	DM13	MISC	Discovery Candidate		10/1/13	11/1/16	11/1/18
DISCOVERY 14	DM14	MISC	Discovery Candidate		9/1/16	9/1/19	9/1/21
New Millennium Deep Space 6	NDS6	MISC	New Millennium Program		7/1/05	7/1/08	7/1/10

Analysis Mission Set Distribution (cont'd)

MISSION NAME	MISSION ID	OSS	PROGRAM	PRGRAM REP	LAUNCH	EOPM	EOEM
MISCELLANEOUS							
New Millennium Deep Space 7	NDS7	MISC	New Millennium Program		7/1/06	7/1/09	7/1/11
New Millennium Deep Space 8	NDS8	MISC	New Millennium Program		7/1/07	7/1/10	7/1/12
SUN EARTH CONNECTION							
Advanced Composition Explorer	ACE	SEC	ASTROPHYSICS	LEDBETTER	08/25/97	08/21/01	08/21/02
CLUSTER	CLUX	SEC	ISTP	LAPIANA	7/1/00	7/1/03	7/1/05
Gravity Probe B	GRVB	SEC	COOP	HUDDLESTON	06/01/96	12/31/01	- - -
Imager for Magnetopause-to-Aurora Global Exploration	IMAG	SEC	MIDEX	HUDDLESTON	1/1/00	1/1/02	- - -
ISTP- Polar	POLR	SEC	ISTP	HOLMES	02/22/96	08/23/97	12/30/01
ISTP- Wind	WIND	SEC	ISTP	HOLMES	11/01/94	11/01/97	12/30/01
ISTP-Geotail	GEOT	SEC	ISTP	HOLMES	07/24/92	07/24/95	12/30/01
ISTP-SOHO	SOHO	SEC	ISTP	HOLMES	12/02/95	03/15/98	03/15/02
New Millennium Deep Space 3	NDS3	SEC	New Millennium Program	LAPIANA	7/1/01	12/1/01	12/1/03
Ulysses	ULS	SEC	COOP	HOLMES	10/06/90	09/11/95	12/30/01
Voyager 1	VG1	SEC	PLANETARY	HOLMES	09/05/77	12/31/80	12/31/19
Voyager 2	VG2	SEC	PLANETARY	HOLMES	08/20/77	10/15/89	12/31/19
STRUCTURE and EVOLUTION of the UNIVERSE							
Advanced X-ray Astrophysics Facility	AXAF	SEU	ASTROPHYSICS	HUDDLESTON	08/27/98	08/30/03	- - -
Highly Advanced Laboratory for Comm	VSOP	SEU	Radio Astonomy	HOLMES	02/12/97	09/30/01	- - -
Internationsl Gamma Ray Astophysics Lab	INTG	SEU	COOP	LAPIANA	4/1/01	4/1/03	4/1/06
Microwave Anisotrpy Probe	MAP	SEU	MIDEX	HUDDLESTON	8/13/00	11/1/01	11/1/04
MIDEX 3	MDX3	SEU	MIDEX Program	HUDDLESTON	1/1/02	12/1/03	12/1/04
RadioAstron	RADA	SEU	RADIOS ASTRONOMY	HOLMES	10/1/98	9/30/01	- - -
Solar Probe	SOLP	SEU	X2000	BREWER	1/16/06	9/5/09	- - -
Space VLBI	SVLB	SEU	RADIO ASTONOMY	HOLMES	02/01/95	09/30/01	- - -
SOLAR SYSTEM EXPLORATION							
Aster 2001 Lander (Mars together candidate)	A01L	SSE	Coop Russia	LAVERY	8/1/01	8/1/04	8/1/06
Aster 2001 Rover (Mars together candidate)	A01R	SSE	Coop Russia	LAVERY	8/1/01	4/1/03	- - -
CASSINI	CAS	SSE	BAJPLM	DAHL	10/06/97	06/30/08	- - -
CHAMPOLLION (NMP DS4)	NDS4	SSE	New Millennium Program	JOHNSTON	4/1/03	5/1/10	5/1/12
Deep Space 2 - Mars microprobes	NDS2	SSE	New Millenium	PIOTROWSKI	1/3/99	12/1/00	- - -
Deep Space 5 (Mars 2003 microseismometer)	NDS5	SSE	New Millennium Program	LAVERY	7/1/04	7/1/07	7/1/09
DISCOVERY 05 (Genesis)	DM05	SSE	Discovery Candidate	LEDBETTER	1/1/01	2/1/02	7/1/02
DISCOVERY 06 (Contour)	DM06	SSE	Discovery Candidate	LEDBETTER	10/1/02	10/1/05	10/1/07
DISCOVERY 15	DM15	SSE	Discovery Candidate		3/1/18	3/1/21	3/1/23
EUROPA LANDER	EURL	SSE	Outer Solar System	LAVERY	4/1/09	4/1/12	4/1/14
EUROPA ORBITER	EURO	SSE	X2000	LAVERY	10/11/02	10/10/07	- - -

Analysis Mission Set Distribution (cont'd)

MISSION NAME	MISSION ID	OSS	PROGRAM	PRGRAM REP	LAUNCH	EOPM	EOEM
SOLAR SYSTEM EXPLORATION							
Galileo	GLL	SSE	PLANETARY	STROBEL	10/18/89	12/07/97	12/31/99
International Cometary Explorer	ICE	SSE	ASTROPHYSICS		08/12/78	08/12/88	12/31/05
IO ORBITER	IORB	SSE	Outer Solar System	LAVERY	8/1/12	9/1/15	7/1/17
JUPITER POLAR ORBITER	JPO	SSE	Outer Solar System	LAVERY	11/1/16	11/1/19	11/1/21
Lunar Prospector	LPM	SSE	Discovery Class	BRODY	11/24/97	11/24/98	04/24/99
Mars 09 Comm Orbiter (Areosync.)	MRLY	SSE	HED	LAVERY	9/1/09	9/1/19	9/1/24
Mars 2007 Comm Obiter	M07O	SSE	Mars Exploration Program	LAVERY	5/1/07	5/1/13	5/1/18
Mars 2009 Sample Return	M9SR	SSE	Mars Exploration Program	LAVERY	10/1/09	10/1/12	- - -
Mars Express 2003 Lander	E03L	SSE	Coop ESA	LAVERY	8/1/03	4/1/05	- - -
Mars Express 2003 Orbiter	E03O	SSE	Coop ESA	LAVERY	8/1/03	8/1/06	8/1/08
Mars Global Surveyor	MGS	SSE	MARS	PIOTROWSKI	11/07/96	01/01/03	- - -
Mars Pathfinder	MPF	SSE	Discovery Class	PIOTROWSKI	12/04/96	08/03/97	07/03/98
MARS SURVEYOR 2001 LANDER	M01L	SSE	Mars Exploration Program	LAVERY	4/5/01	1/27/02	- - -
MARS SURVEYOR 2001 ORBITER	M01O	SSE	Mars Exploration Program	LAVERY	3/7/01	12/10/06	- - -
MARS SURVEYOR 2003 LANDER	M03L	SSE	Mars Exploration Program	LAVERY	5/28/03	12/25/03	- - -
MARS SURVEYOR 2003 OBITER	M03O	SSE	Mars Exploration Program	LAVERY	5/5/03	11/6/08	- - -
MARS SURVEYOR 2005 SAMPLE RETURN	M05S	SSE	Mars Exploration Program	LAVERY	11/5/04	5/1/08	- - -
Mars Surveyor 2007 Lander (w ISRU)	M07L	SSE	Mars Exploration Program	LAVERY	9/1/06	6/1/09	- - -
Mars Surveyor 98 Orbiter	M98O	SSE	MARS	PIOTROWSKI	12/10/98	01/04/05	- - -
MarsSurveyor 98 Lander	M98L	SSE	MARS	PIOTROWSKI	01/03/99	02/29/00	- - -
MULTI-PROBE NETPTUNE	MPN	SSE	Outer Solar System	LAVERY	1/1/16	1/1/19	1/1/21
MULTI-PROBE SATURN	MPS	SSE	Outer Solar System	LAVERY	3/1/13	3/1/16	3/1/18
MULTI-PROBE URANUS	MPU	SSE	Outer Solar System	LAVERY	1/17/14	4/15/20	4/1/22
MUSES-C	MUSC	SSE	COOP Japan	LAVERY	1/7/02	1/21/06	- - -
MUTLI-PROBE JUPITER	MPJ	SSE	Outer Solar System	LAVERY	8/1/08	2/1/12	2/1/14
Near Earth Asteroid Rendezvous	NEAR	SSE	Discovery Class	LEDBETTER	02/17/96	02/06/00	- - -
NEPTUNE ORBITER	NEPO	SSE	Outer Solar System	LAVERY	5/1/10	4/1/14	4/1/16
New Millennium Deep Space 1	DS1	SSE	New Millennium Class	LEDBETTER	07/01/98	08/01/00	07/01/02
Planet B	PLNB	SSE	COOP	DAHL	08/04/98	10/01/01	- - -
Pluto Express	PEX	SSE	X2000	ULRICH	12/15/04	1/15/15	- - -
ROSETTA	ROSE	SSE	COOP ESA	ULRICH	1/22/03	7/7/13	- - -
SATURN RING ORBITER	SRO	SSE	Outer Solar System	LAVERY	8/1/17	8/1/20	8/1/22
Stardust	STAR	SSE	DISCOVERY	DAHL	02/06/99	01/14/06	- - -
TITAN AEROBOT	TABT	SSE	Outer Solar System	LAVERY	2/1/12	2/1/15	2/1/17

Total Network Capacity Assumptions

- Estimated network tracking hour capacity
  - Based on experience
  - Utilization of network assets at 67% of available wall clock hours
    - Best case for average across all assets

  - Assumed assets include
    - 70 meter subnet, DSS-14, 43, 63
    - 34 meter Standard antenna, DSS-42, DSS-61
    - 34 meter High Efficiency subnet, DSS-15, 45, 65
    - 34 meter Beam Waveguide subnets, 1 & 2
      - DSS-24, 34, 54
      - DSS-25, 26
    - 34 meter High Speed Beam Waveguide, DSS-27

  - Estimated Supportable Hours for these assets in 1998 is:
    - 71,750 hours

  - Total estimated number of hours supported by the network in 1998 is:
    - 92,000 hours
    - Includes 21,250 hours contributed by:
      - 26 meter subnet, 11 meter subnet and Goldstone 9 meter

JPL

Growth Potential

- Both the RF and optical capacity metrics are based on a fixed set of assumptions about flight and ground technology
- Significant future growth is available:
  - RF:
    - Improved DSN low-noise amplifiers, esp for Ka-band
    - Larger spacecraft antennas
      - 2m antenna provides 4x increase
      - 3-10 m inflatable provides ~10-100x increase (pointing and surface issues, particularly at Ka-band)
    - Higher power amplifiers
      - X-band TWTAs to 100 W with efficiency >60%
      - Ka-band TWTAs to 40 W with efficiency >50%
  - Optical:
    - Improved detector efficiency (40% -> 80% w/ High-QE Visible Light Photon Counter)
    - Higher-power, more efficient s/c laser transmitter
    - Larger spacecraft aperture (30 cm -> 1 m provided order-of-magnitude improvement)
    - Shorter wavelength (1064 nm -> 532 nm provides 4x improvement)
    - Earth-orbiting receive station (order-of-magnitude improvement by eliminating atmospheric effects)

Ka-band Spectrum Issues

- **The band 31.8 - 32.3 GHz is currently allocated to deep-space downlink telemetry (SPACE RESEARCH)**
- **There are two other co-allocated users of of this spectrum band**
  - **RADIONAVIGATION (32.0-33.4 GHz)**
    - **Aeronautical terrain following radar**
      - **Current use is by DoD**
        - **Agreements in place w/ DoD to protect Goldstone and other DSN locations**
        - **DoD insists on use of the entire 1.4 GHz band elsewhere**
      - **Interest in using this equipment on commercial aircraft**
        - **NASA lobbying FAA and SFCG to restrict this use to above 32.3 GHz**
  - **INTER-SATELLITE SERVICES (32.0-33.0 GHz)**
    - **NASA lobbying to restrict this use to above 32.3 GHz**
    - **Attempting to get this issue on the WRC 2001 agenda**
- **NASA must vigorously defend its Ka-band SPACE RESEARCH allocation in the coming years**

Potential Leased Optical Facilities

- **Below are the telescopes with apertures larger than 4-m that are possible candidates for lease. Most of the large 8-m telescopes are reported to be ready to see first light in 2002 including the 10-m in the Canary islands.**

Facility	Diameter (m)	Location
Mayall	4	AZ
Isaac Newton Telescope (INT)	4.2	Canary Islands
Multiple Mirror Telescope (MMT)	4.5	AZ
Hale	5	Palomar CA
Subaru	8	Hawaii
Gemini	8	Hawaii
Gemini	8	Chile
Very large Telescope (VLT)	4 x 8.2	Chile
Large Binocular Telescope (LBT)	2 x 8.4	AZ
Keck	2 x10	Hawaii
Gran Telescopio Canarias (GTC)	10	Canary Islands

- **The details of how we would mount the receiver instrument to these telescopes will require further work, and may eliminate some of these as candidates.**

Optical Comm Roadmap Options

- **Baseline optical comm roadmap for Europa assumes:**
  - **One dedicated site (10m photon bucket plus 1m uplink)**
  - **One add'l borrowed receive-only site (for site diversity, robustness, and increased data return)**
  - **Total cost is $60.6M**
  - **Note: Any req'd lease costs for borrowed site <u>not</u> included in estimate**
- **Considered two descope options:**
  - **Downlink-only: reduces total cost to $52.0M**
  - **Downlink-only, with two borrowed sites: reduces total cost to $19.9M**
  - **Note: Still assessing feasibility of downlink-only architecture; requires ability to point using sunlit Earth as pointing reference**

Real-Year $M	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	TOTAL
Basline Option:											
Optical 1m R&D	0.749	1.800	0.261	0.110	0.000	0.000	0.000	0.000	0.000	0.000	2.920
1st 10 m Optical (w/ 1m uplink)	0.000	0.000	1.327	2.925	23.771	11.168	6.051	3.913	0.000	0.000	49.154
Borrowed 10m	0.000	0.000	0.000	0.000	0.000	0.000	0.382	2.277	3.117	2.702	8.478
TOTAL:	**0.749**	**1.800**	**1.588**	**3.035**	**23.771**	**11.168**	**6.433**	**6.189**	**3.117**	**2.702**	**60.552**
Downlink-only Option:											
Optical 1m R&D	0.749	1.800	0.261	0.110	0.000	0.000	0.000	0.000	0.000	0.000	2.920
1st 10 m Optical (w/out 1m uplink)	0.000	0.000	1.327	3.013	25.218	3.185	4.080	3.772	0.000	0.000	40.595
Borrowed 10m	0.000	0.000	0.000	0.000	0.000	0.000	0.382	2.277	3.117	2.702	8.478
TOTAL:	**0.749**	**1.800**	**1.588**	**3.123**	**25.218**	**3.185**	**4.462**	**6.049**	**3.117**	**2.702**	**51.992**
Borrowed-only, Downlink-only Option:											
Optical 1m R&D	0.749	1.800	0.261	0.110	0.000	0.000	0.000	0.000	0.000	0.000	2.920
First Borrowed 10m	0.000	0.000	0.000	0.000	0.000	0.000	0.382	2.277	3.117	2.702	8.478
Second Borrowed 10m	0.000	0.000	0.000	0.000	0.000	0.000	0.382	2.277	3.117	2.702	8.478
TOTAL:	**0.749**	**1.800**	**0.261**	**0.110**	**0.000**	**0.000**	**0.764**	**4.553**	**6.233**	**5.405**	**19.875**